# The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture

**Daniel G. De La Torre Ugarte**
**Marie E. Walsh**
**Hosein Shapouri**
**Stephen P. Slinsky[1]**

**July, 2000**

[1] Authors are Research Assistant Professor at the University of Tennessee Agricultural Policy Analysis Center (APAC), Economist at the Oak Ridge National Laboratory, (DOE-ORNL); Economist at the Office of Energy Policy and New Uses (USDA-OEPNU); and Research Associate at APAC.

**The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture.**
By Daniel G. De La Torre Ugarte, Research Assistant Professor at the University of Tennessee Agricultural Policy Analysis Center (APAC); Marie E. Walsh, Economist at the Oak Ridge National Laboratory (DOE-ORNL); Hosein Shapouri, Economist at the Office of Energy Policy and New Uses (USDA-OEPNU); and Stephen P. Slinsky, Research Associate at the University of Tennessee Agricultural Policy Analysis Center (APAC).

# Abstract

The oil embargoes of the 1970s raised concerns about energy security. Today, concerns about the environmental impacts associated with fossil fuel use, particularly potential global climate change, have added new immediacy to the development of alternative energy systems. Biomass energy systems using dedicated bioenergy crops are among the alternative systems under development. The large scale production of bioenergy crops could have significant impacts on the United States agricultural sector in terms of quantities, prices and production location of traditional crops as well as farm income. To examine these potential impacts and to evaluate the prices that would be required to make bioenergy crops competitive with traditional crops, the United States Departments of Energy and Agriculture, in collaboration with The University of Tennessee and the Oak Ridge National Laboratory, modified an agricultural sector model (POLYSYS) to include switchgrass, hybrid poplar, and willow. The analysis also examined the potential to use Conservation Reserve Program (CRP) acreage as a source of bioenergy crops under two management scenarios: one to achieve high biomass production and one to achieve high wildlife diversity. Under the wildlife management scenario, the analysis indicates that, at $30/dry ton (dt) for switchgrass, $31.74/dt for willow and $32.90 for poplar, an estimated 19.4 million acres of cropland (8.2 million from CRP) could be used to produce 96 million dry tons of bioenergy crops annually at a profit greater than the profit created by existing uses for the land. In this scenario traditional crop prices increase from 3% to 9% (depending on crop) and net farm income increases by $2.8 billion annually. At $40/dt of switchgrass, $42.32/dt for willow and $43.87/dt for poplar and assuming the production management scenario, an estimated 41.9 million acres (12.9 million from CRP) could be used to produce 188 million dry tons of biomass annually. Under this scenario, traditional crop prices increase by 8 to 14% and net farm income increases by $6 billion annually.

**Keywords:** Alternative crops, bioenergy crops, biomass, Conservation Reserve Program, crop acreage shifts, crop budgeting, economic feasibility, economic impact, hybrid poplars, hybrid willow, POLYSYS, switchgrass

# Contributors

The contributors to this study include: Dr. Larry Abrahamson, (State University of New York); Dr. Mike Anderson, (USDA-NRCS); Dr. Samuel Baldwin, (Office of Science and Technology Policy); Dr. Alex Barbarika, (USDA-FSA); Dr. Dwayne Buxton, (USDA-ARS-NPS); Dr. Liu-Hsiung Chuang, (USDA-NRCS); Dr. Roger Conway, (USDA-OEPNU); Ms. Janet Cushman, (DOE-ORNL); Mr. John Ferrell, (DOE); Dr. Robin Graham, (DOE-ORNL); Dr. Malcolm Henning, (USDA-NRCS); Dr. John Hom, (USDA-FS); Dr. Jud Isebrands, (USDA-FS); Dr. Sandy McLaughlin, (DOE-ORNL); Mr. Tien Nguyen, (DOE); Mr. Rick Pierce, (Champion International); Dr. Edward Rall, (USDA-FSA); Dr. Daryll Ray, (APAC); Dr. Dan Robison, (North Carolina State University); Dr. Mark Safley, (USDA-NRCS); Dr. John Stierna, (USDA-NRCS); Mr. Mike Sullivan, (Champion International); Dr. Keith Tamiguchi, (DOI-FWS); Mr. Alan Teel, (Iowa State University); Dr. Keith Ticknor, (USDA-NRCS); Dr. Kelly Tiller, (APAC); Dr. Jerry Tuskan, (DOE-ORNL); Dr. Ken Vogel, (USDA-ARS); and Ms. Lynn Wright, (DOE-ORNL).

# Table of Contents



# List of Figures



# List of Tables

# The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture

## Chapter I: **INTRODUCTION**

The oil embargoes of the 1970s raised concerns about energy security. In response, programs to develop alternative energy sources were begun. While energy security still remains a concern, the potential threat of global climate change resulting from the use of fossil fuels has added new immediacy to the development of alternative energy systems. Biomass energy systems are among the alternatives being developed to provide energy into the 21$^{st}$ Century. Life cycle assessments indicate that biomass energy systems can be energy efficient, significantly reduce greenhouse gas emissions relative to fossil energy, and provide other environmental benefits (DeLucchi, M.A.; Wang, M., Saricks, C., and Santini, D.; Mann, M.K., and Spath, P.L.)

Several biomass energy systems are nearing commercialization. The first cellulose-to-ethanol plant is currently under construction in Louisiana and two additional facilities are in the planning and financing stages. Advanced biomass gasification systems for electricity generation are being tested at two sites and co-firing tests (i.e., mixing biomass with coal in coal-fired electrical generation facilities) are being conducted at numerous sites throughout the United States. These early facilities will rely, predominantly, on waste biomass materials such as logging residues, wood processing mill residues, urban wood wastes, and selected agricultural residues such as sugar cane bagasse and rice straw as their biomass feedstock. However, these feedstocks are available in limited quantities. For the biomass industry to expand to represent a significant portion of the primary energy consumed in the United States, additional feedstocks will need to be utilized. Recognizing this fact, in 1978 the U.S. Department of Energy (DOE) established the Bioenergy Feedstock Development Program (BFDP) at the Oak Ridge National Laboratory (ORNL).

The BFDP is engaged in the development of new crops and cropping systems that can be used as dedicated bioenergy feedstocks. The program has screened numerous potential crop candidates to identify promising species. Research activities frequently involve collaborative efforts with university and United States Department of Agriculture (USDA) researchers. While numerous herbaceous and woody crop species could be used as bioenergy crops, and in some geoclimatic situations might be preferred, this analysis focuses on switchgrass, hybrid poplar and willow. The rationale for this focus includes the facts that these crops receive the greatest research funding and their management practices are similar to several of the other potential bioenergy crops being evaluated. Thus they can serve as a general model for many other potential bioenergy crops.

Switchgrass (*Panicum virgatum*), is a perennial warm season grass. Its native range includes the United States east of the Rocky Mountains and extends into Mexico and Canada. It is a dominant species of the remnant tall grass prairies in the United States. Switchgrass is genetically diverse and includes both lowland and upland varieties. Currently, switchgrass is grown on limited acreage in the Conservation Reserve Program (CRP) and as a forage crop. Existing research plots have produced yields as high as 15 dry tons per acre per year (dt/ac/yr) and have averaged over 10 dt/ac/yr for six years. The potential to increase yields is viewed as high. Switchgrass can be planted, managed and harvested in a manner similar to traditional hay crops using existing agricultural equipment.

Poplar (*Populus spp.*) is widely distributed throughout the United States and includes both aspen and cottonwood species. Many of the poplar varieties being developed for commercial use are crosses between two or more Populus species that provide hybrid vigor to the offspring. Currently, hybrid poplar is commercially produced on about 200,000 acres for use by the paper and pulp industry. In commercial stands in the Pacific Northwest, hybrid poplar trees have reached harvestable size (8 inch diameter breast height) in 6-7 years. At selected research sites, mean annual incremental yields of as high as 15 dt/ac/yr for a complete production cycle have been obtained using improved varieties. Hybrid poplar can be planted and managed with existing agricultural equipment and can be harvested with existing forestry equipment.

Willow (*Salix spp.*) can be grown throughout the eastern United States. However, suitable varieties and appropriate management practices required for large-scale commercial production in the Plains and Southern United States regions have not yet been developed. The willow plants used for energy production are hybrid shrubs, rather than the trees often associated with the species. Willow production is expected to involve a close-spaced, coppice system developed predominantly in Europe, where willow is being commercially produced for energy. Yields as high as 12 dt/ac/yr have been achieved in research plots in the United States. Planting and harvesting of willow utilize specially designed machinery that is commercially available in Europe.

The production of switchgrass, hybrid poplar, and willow utilizes agricultural management practices that are similar to those used in traditional crop agriculture and forest plantations. In this study production is assumed to occur on agricultural croplands. Thus, bioenergy crops must compete economically with traditional crops. As a result, large-scale production of bioenergy crops could have important implications for the agricultural sector in terms of crop prices and farm income. To address these issues, the DOE Office of Transportation Technologies and USDA, in collaboration with the University of Tennessee Agricultural Policy Analysis Center (APAC) and ORNL, have jointly evaluated the potential economic feasibility and ramifications of bioenergy crop production in the United States. For the study, an agricultural sector model (POLYSYS), which was developed and maintained by APAC and used by the USDA Economic Research Service (USDA-ERS), has been modified to include switchgrass, hybrid poplar, and willow. The analysis seeks, at a macroeconomic level, to:

- Estimate the farmgate price needed to make bioenergy crops economically competitive with alternative agricultural uses for cropland,
- Determine the regional distribution of bioenergy crop production,
- Estimate the potential impact of bioenergy crop production on traditional crop prices and quantities,
- Estimate the potential impact of bioenergy crop production on net farm income, and
- Evaluate the economic potential of a modified CRP to serve as a land resource for bioenergy crop production.

The CRP program has been suggested as a means to introduce bioenergy crops to the agricultural sector. The CRP contract length roughly corresponds to the production cycle of bioenergy crops. Production of bioenergy crops on CRP acres could potentially provide a stable supply of feedstocks to user facilities, and income to producers through continued receipt of partial rental payments and the sale of bioenergy crops, while potentially lowering the cost of the CRP program to the federal government. The partial support of bioenergy crops could help lower their price and improve their attractiveness to user facilities.

However, the CRP program is an environmental program. If it is to be used as a source of bioenergy crops, the production and harvest of these crops must be conducted in a manner that maintains the environmental benefits of the program. Criteria must be developed that identify acres suitable for bioenergy crop production. Management practices must be developed that minimize the loss of environmental benefits while still providing an economic incentive to producers. This study makes a first attempt at addressing these issues. Those CRP acres which have been identified as most environmentally sensitive are eliminated from consideration for bioenergy crop production. Additionally, a first attempt to analyze the economic impacts of different bioenergy crop management strategies is made.

The following chapters describe the POLYSYS model, the modifications made to the POLYSYS model to accommodate inclusion of bioenergy crops, and the results of the analysis for two price and bioenergy crop management strategies. Appendices detail traditional crop management data sources and describe the management practices and estimated production costs assumed for bioenergy crops.

# Chapter II: **METHODOLOGY**

## The POLYSYS Model

The analysis uses POLYSYS, an agricultural policy simulation model of the United States agricultural sector that includes national demand, regional supply, livestock, and aggregate income modules (De La Torre Ugarte and Ray, 2000). POLYSYS is anchored to published baseline projections for the agricultural sector and the model simulates deviations from the baseline. Typically POLYSYS uses the USDA, Food and Agriculture Policy Research Institute (FAPRI) or Congressional Budget Office (CBO) baseline for Unites States agriculture.

The regional crop supply module consists of independent linear programming models for each of the 305 geographic regions contained in POLYSYS corresponding to the 305 Agricultural Statistical Districts (ASD). Each ASD is characterized by relatively homogenous production. The core POLYSYS model includes the eight major crops (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice) as well as some minor crops (peanuts, sugar cane, sugarbeets, dry beans) but can be modified to include additional crops or exclude some of the core commodities. As with all the other modules, the crop supply module is anchored to a national baseline which is disaggregated to a regional level based on historical crop production and supply patterns. Once the total acres available for crop production in each ASD is determined (baseline acres and short and long term land retirement programs), the supply module allocates acres to competing crops using a linear programming model that maximizes expected returns using expected crop prices (to be described later). Production from each of the 305 ASDs is determined independently and aggregated to obtain national production. Allocation rules are utilized to limit the acreage that can be switched from production of one crop to another or removed from production in each ASD. These allocation rules prevent corner solutions and simulate the inelastic nature of agricultural supply.

The core POLYSYS model estimates expected returns in one of two ways: a weighted average of prices in the last three years or as the previous year's price. Expected returns per acre for each crop include revenues, based on the expected prices and the baseline or hypothesized yield, and a range of expenditures, used to compute the variable and cash costs. The core model uses enterprise budgets for each crop in each ASD. Rotational budgets can be incorporated into any given study.

The crop supply module solves for the optimal allocation of cropping activities in each region, given the allocation rules established. The estimated supply quantity interacts with the crop demand module to estimate new prices, demand quantities, and carryover stocks for the current time period.

The livestock module is an econometric model which interacts with the crop supply and demand modules to estimate livestock production, feed use, and market prices. Livestock production levels are a function of lagged livestock and feed own and cross prices, as well as the baseline levels and exogenously determined variables such as livestock exports. The livestock sector is linked to the supply and demand modules principally through the feed grain component. Livestock quantities affect feed grain demand and price, and feed grain prices and supply affect livestock production decisions. Exports and imports of livestock products are exogenous to the model.

The crop demand module estimates national level demand quantities and prices using elasticities and changes in baseline prices. Crop utilization is estimated for domestic demand (food, feed, and industrial uses), exports, and stock carryovers. Derivative products such as soybean oil and meal are also included. Demand quantities are estimated as a function of own and cross prices and selected non price variables such as livestock production. The crop prices are estimated using price flexibilities and stock carryovers are estimated as the residual element.

The income module uses information from the crop supply, crop demand, and livestock modules to estimate cash receipts, production expenses, government outlays, net returns, and net realized farm income.

To evaluate the economic potential of bioenergy crops, several modifications to the core POLYSYS model are made. Acres planted to alfalfa and other hay crops are incorporated into the model as are cropland acres currently enrolled in the CRP program and acres that are idled or in pasture. Geographic areas suitable for the production of bioenergy crops are identified and production practices and yields for these crops are incorporated into the model. The land allocation rules in POLYSYS are modified to account for the potential production of bioenergy crops. In order to allow producers to include in their decision framework any anticipated price changes that might result from significant shifts of acres to bioenergy crops, a rational expectations price formulation is incorporated. Each is discussed in greater detail in the following sections.

## Cropland Categories

According to the 1997 Census of Agriculture, 431.4 million acres are identified as cropland in the United States. Seventy three percent of these acres is currently in major crop production (including alfalfa and other hay). The re-

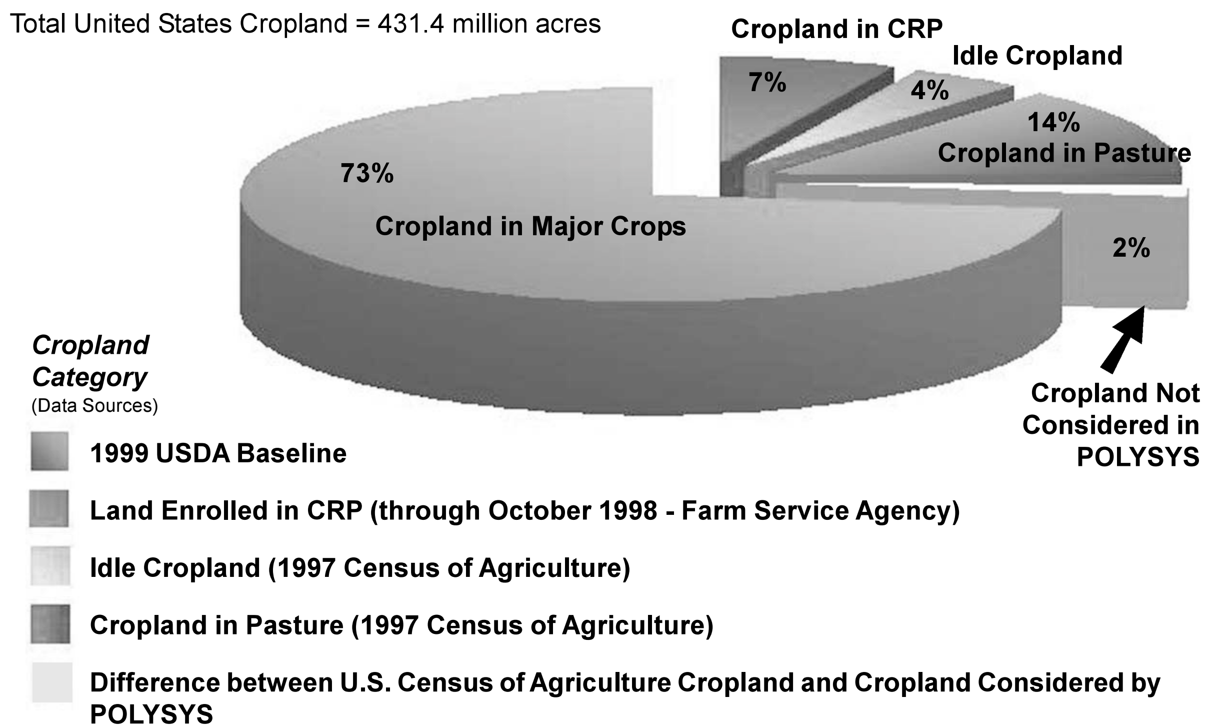


**Figure 1. Cropland Categories**

maining cropland acres are idled (4%), in pasture (14%), enrolled in the Conservation Reserve Program (7%), or in other uses such as in the production of fruits, vegetables, or other minor crops (2%) (Figure 1). According to the 1999 USDA Baseline, 254.5 million cropland acres are planted to the eight major crops. The 1999 FAPRI Baseline estimates that 27.2 million cropland acres are planted to alfalfa and 33.2 million cropland acres are planted to other hay crops. A total of 29.8 million cropland acres are enrolled in the Conservation Reserve Program (Farm Services Agency, October 1, 1998). The 1997 Census of Agriculture estimates that 19.0 million cropland acres are idled with 60.3 million cropland acres planted to pasture. The version of POLYSYS used to evaluate bioenergy crops includes all of these cropland acres. POLYSYS does not include cropland acres allocated to fruits and vegetables and minor crops such as dry beans, sugar cane and beets, tobacco, etc., which total 2% of all United States cropland.

The acres included in POLYSYS represent the cropland acres in the forty-eight contiguous states. Bioenergy crops can grow in all regions of the United States. However, for the purpose of this analysis, the geographic ranges where production can occur are limited to areas where bioenergy crops can be produced with high productivity under rain fed conditions and where sufficient research has been conducted to make informed decisions regarding suitable varieties, appropriate management practices, and expected yields. The regions analyzed include those where sufficient knowledge of each bioenergy crop has been accumulated to reasonably expect that large-scale commercial production could begin during the time frame considered in the analysis, 1999-2008. The production regions could be expanded in the future as research is conducted in other geographic regions. The switchgrass, hybrid poplar, and willow production regions used in this analysis are presented in Figures 2 to 4.

With respect to the Conservation Reserve Program acres, geographic limitations reduce the number of acres from the enrolled 29.8 million acres (as of October 1, 1998) to 24.1 million acres. These acres are further restricted to remove from consideration for bioenergy production those acres that are most environmentally sensitive. These CRP acres include (1) acres enrolled in buffer strips to protect water quality, (2) acres classified as wetlands, (3) acres critical to watershed management, and (4) critical habitat acres in Wildlife Conservation Priority Areas. These restrictions remove an additional 7.2 million CRP acres. Thus, for this analysis, 16.9 million CRP acres are identified as being potentially available for bioenergy crop production (Figure 5).

A summary of the cropland, by category, that is included

**Figure 2. ASDs in which production of switchgrass is assumed**

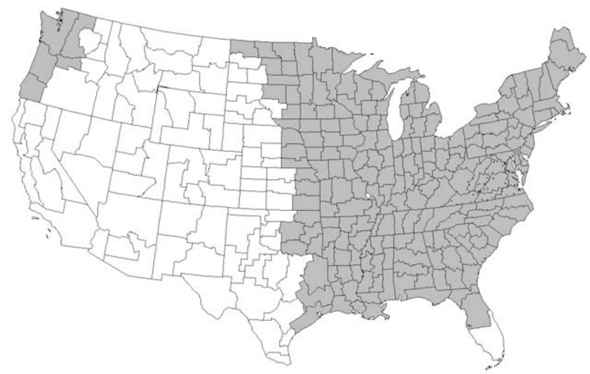

**Figure 3. ASDs in which production of hybrid poplar is assumed**

**Figure 4. ASDs in which production of willow is assumed**

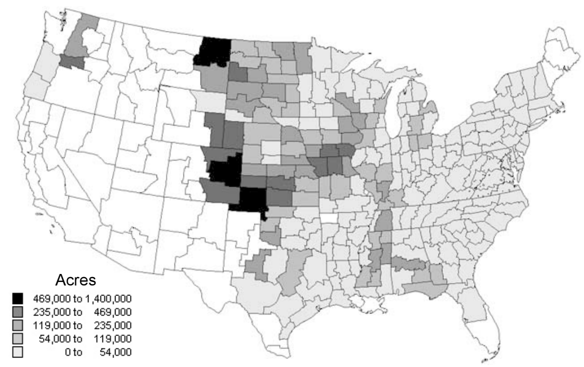


**Figure 5. Distribution of CRP acres assumed potentially available for bioenergy production as of October 31, 1998**

in POLYSYS is presented in Table 1. The production of at least one of the bioenergy crops included in this analysis is assumed suitable on 368 of the total 424 million acres included in POLYSYS.

## Crop Production Costs

The bioenergy crops analyzed in this study are not currently produced as dedicated energy sources in the United States. However, about 200,000 acres of hybrid poplar are being commercially produced as a fiber source and switchgrass is grown on some CRP acres and on hay acres as a forage crop. The lack of large-scale commercial production necessitates the use of research data and expert opinion to determine yields and management practices. Before beginning the analysis, experts from the U.S. Departments of Energy and Agriculture participated in a workshop (Appendix 1) where recommendations were made regarding:

- Geographic regions assumed for bioenergy crop production;
- Current and projected bioenergy crop yields by geographic region;
- Management practices appropriate for bioenergy crop production by land type and geographic region.

Geographic regions and yields are based predominately on those contained in the Oak Ridge Energy Crop County Level Database (Graham, et al, 1996) and modified by the recommendations of the workshop participants. Bioenergy crop yields, by ASD, range from 2 dt/ac/yr to 6.75 dt/ac/yr depending on crop and location within the United States. Yields of bioenergy crops on idled and pasture acres are assumed to be 85% of those that can be obtained on acres in crop production. Bioenergy crop yields on CRP acres are adjusted by an index of traditional crop yields obtained on CRP acres prior to being enrolled in the CRP.

Once planted, the expected yields for bioenergy crops remain fixed for the life of the production rotation. Research is ongoing to improve yields. As a result, acres planted in later years could be assumed to have higher yields than those planted in earlier years.

Production costs for all crops considered in the analysis (i.e., traditional and bioenergy) are estimated using enterprise budgets. All production costs, except willow and hybrid poplar harvesting costs, are estimated using the APAC Budgeting System (ABS) (Slinsky and Tiller, 1999). ABS generates consistent enterprise and rotation budgets for each of the 305 ASDs contained in POLYSYS. Use of this budgeting system to estimate the costs of producing bioenergy crops as well as traditional crops ensures consistency across all crops in the analysis. ABS generates cost of production data based on operations schedules (i.e., field-level activities). The schedule of operations used for each traditional crop for each region is based on Agricultural Extension Service publications whenever possible. The resolution of information (state or substate level) provided in each budget varies according to the level at which particular information is available. Appendix 2 contains information regarding traditional crop management data sources.

Crop management practices for bioenergy crops produced on cropped, idle, and pasture acres are based on recommendations from the expert panel. These practices are presented in Appendices 3.1 and 3.2. Bioenergy crop management practices used on CRP acres were determined in subsequent discussions with USDA (Natural Resource Conservation Service and Farm Service Agency). Two CRP management practices were decided on for use in the analysis: one to achieve high levels of biomass production (production management scenario), and one to achieve high levels of wildlife diversity (wildlife management scenario). These management practices are described in Appendix 3.3. Generally, the wildlife management scenario utilizes fewer fertilizer and chemical inputs than does the production management scenario. It also places significantly greater constraints on the harvest of switchgrass by restricting harvest to alternating halves of a field each year to provide variations in physical structure as compared to annual harvest of the whole field in the production management scenario.

Estimated production costs for all crops include variable cash input costs (chemicals, fertilizers, seeds, cuttings, fuel and lubrication, machinery repair, hired labor, loan interest payments, etc.), producer's own labor, and machinery related costs (such as depreciation, insurance, and non-land capital costs). Machinery related costs are estimated by first defining all equipment needed to complete each field operation as specified by the management practices for each crop. Labor costs are estimated as a function of machinery hours. Machine costs per hour of operation are estimated using standard methodology (USDA, American Society of Agricultural Engineers) and multiplied by the hours per acre required to complete each operation to obtain the cost of the machinery per acre. Machinery prices and engineering performance parameters were obtained from the USDA (McBride) for all equipment except that used for harvesting hybrid poplar and willow. These costs were estimated using BIOCOST, a budget generator model developed by Oak Ridge National Laboratory to estimate the cost of producing bioenergy crops (Walsh and Becker, 1996). BIOCOST is used to estimate hybrid poplar and willow harvesting costs because neither the USDA database nor ABS includes data on forest harvesting equipment. The methodologies, input prices, and the cost categories used in BIOCOST are consistent with ABS.

The management practices used to estimate production costs are those that are typical for that ASD. They are not necessarily those used on every individual farm or soil type within a farm. Thus, the production costs used in the analysis are representative average costs for each ASD. Variation in production practices, yields, and labor and equipment constraints at an individual farm or field level within an ASD may occur which could alter the estimated costs of production for that site. These variations are not

| | POLYSYS Acreage (Mil. Acres) | Acres Assumed Suitable for Bioenergy Crop Production (Mil. Acres) | (% of Total Acres) |
|---|---|---|---|
| Major Crops* | 314.9 | 282.5 | 89.7% |
| CRP | 29.8 | 16.9 | 56.7% |
| Idle | 19.0 | 14.7 | 77.4% |
| Pasture | 60.3 | 53.8 | 89.2% |
| TOTAL** | 424.0 | 367.9 | 86.8% |

* Includes corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, alfalfa, and other hays.
** Excludes 7.4 million acres in other uses such as fruits, vegetables and other minor crops.

**Table 1. Summary of Cropland in POLYSYS**

| | NE | APP | CB | LS | SE | SP | NP | PNW |
|---|---|---|---|---|---|---|---|---|
| **Switchgrass** | | | | | | | | |
| Yield (dt/ac/yr) | 4.87 | 5.84 | 5.98 | 4.80 | 5.49 | 4.30 | 3.47 | - |
| Yield Range (dt/ac/yr) | 3.50-5.50 | 4.36-6.62 | 4.95-6.73 | 3.50-6.00 | 3.40-6.45 | 2.55-5.98 | 2.00-5.49 | - |
| Avg. Prod. Cost ($/ac) | 983.14 | 969.50 | 975.75 | 863.10 | 929.73 | 847.37 | 714.25 | - |
| Avg. Prod. Cost ($/dt) | 22.53 | 18.53 | 18.21 | 20.07 | 18.90 | 21.99 | 22.97 | - |
| Prod. Cost Range ($/dt) | 21.38-25.10 | 17.21-20.89 | 17.63-18.76 | 18.91-23.32 | 17.87-23.70 | 16.87-29.44 | 18.73-36.20 | - |
| **Hybrid Poplar** | | | | | | | | |
| Yield (dt/ac/yr) | 3.99 | 3.56 | 4.63 | 4.41 | 4.50 | 3.75 | 3.83 | 5.73 |
| Yield Range (dt/ac/yr) | 3.43-4.50 | 4.00-5.21 | 3.75-5.20 | 3.50-5.25 | 3.82-5.21 | 3.25-4.00 | 3.25 -4.31 | 5.50-6.00 |
| Avg. Prod. Cost ($/ac) | 920.38 | 967.56 | 917.26 | 892.82 | 967.57 | 928.78 | 900.74 | 1051.08 |
| Avg. Prod. Cost ($/dt) | 23.07 | 27.18 | 19.81 | 20.25 | 26.88 | 30.96 | 23.52 | 30.57 |
| Prod. Cost Range ($/dt) | 20.87-29.21 | 24.03-29.59 | 23.18-18.74 | 17.72-24.40 | 23.95-30.13 | 29.49-34.57 | 22.25-26.67 | 29.56-31.59 |
| **Willow** | | | | | | | | |
| Yield (dt/ac/yr) | 4.90 | 4.50 | 4.70 | 4.60 | - | - | - | - |
| Yield Range (dt/ac/yr) | 3.15-5.77 | 4.50-4.50 | 4.50-5.08 | 4.05-5.25 | - | - | - | - |
| Avg. Prod. Cost ($/ac) | 2206.33 | 2163.74 | 2161.30 | 2154.30 | - | - | - | - |
| Avg. Prod. Cost ($/dt) | 20.47 | 21.86 | 20.90 | 21.29 | - | - | - | - |
| Prod Cost Range ($/dt) | 17.77-30.46 | 21.86-21.86 | 19.51-21.71 | 18.95-23.88 | - | - | - | |

NE = CT, NH, NJ, NY, MA, ME, PA, RI, VT
APP = DE, KY, MD, NC, TN, VA, WV
CB = IA, IL, IN, MO, OH
LS = MI, MN, WI
SE = AL, AR, FL, GA, LA, MS, SC
SP = CO, KS, NE, OK, TX
NP = MT, ND, SD, WY
PNW = OR, WA
Yield = Mature Yield
Production Costs ($/ac & $/dt) = Present value cost over entire rotation

**Table 2: Regional Bioenergy Crop Production Costs and Yields, Average and Range**

captured in the analysis.

Based on the assumed yield, management practices, and input costs used in the analysis, switchgrass is relatively the least expensive bioenergy crop to produce per dry ton yield for most ASDs. Hybrid poplar is next and willow is generally the most expensive. Table 2 contains the estimated regional average and range of production costs and yields for bioenergy crops.

The production costs are the present value cost (assuming a real discount rate of 6.5%) of producing the bioenergy crop (in $/ac and $/dry ton) for its entire production rotation. Production rotations are 10 years for switchgrass, 6 to 10 years for poplar, and 22 years for willow. The net present value framework is discussed in more detail in the following section. Production costs are those estimated for cropland acres currently planted to crops. Production costs for idle, pasture, and CRP acres are generally higher for each bioenergy crop.

Given that the estimated average per ton production costs for switchgrass are generally lower than for the tree crops in most ASDs, at similar market prices ($/dt) for the three bioenergy crops, switchgrass will be relatively more profitable than poplar and willow. As a result, POLYSYS allocates most of the bioenergy crop acres to switchgrass. Poplar and willow are generally more expensive to produce due to the higher establishment costs and the long period of time before returns from harvest are sufficient to pay for establishment, requiring interest payments to be carried for several years. In a present value framework, costs incurred in the first few years are weighed more heavily than those incurred in later years. Appendix 4 contains a more detailed breakdown of the regional average bioenergy crop production costs.

## Production Decision Issues

As annuals, traditional agricultural crops are planted and harvested each year. The bioenergy crops examined in this study are perennials that are planted in one year and remain in production for several years after planting. Harvest can occur annually during the production cycle (e.g., switchgrass), multiple times at defined intervals during a production cycle (e.g., willow), or once at the end of a production cycle (e.g., hybrid poplar). Due to the multi-year characteristics of bioenergy crops, a net present value (NPV) approach is used to decide which crop to produce. This differs from the original mechanism embodied in POLYSYS, which utilizes annual net returns to allocate acres among the traditional crops.

To evaluate whether a bioenergy crop should be planted in a particular region, its expected net present value profit is calculated and compared to the corresponding expected net present value profit for each of the traditional crops. Acreage is allocated to each crop (traditional as well as bioenergy crops) based on relative NPV profits subject to flexibility constraints described in the next section. Given that the three bioenergy crops examined in this study have production cycles of different time lengths, a common planning horizon is used to ensure comparability of discounted revenue streams. A total planning horizon of 40 years is set because, although not a minimum common denominator, it spans a long enough time period to consider insignificant the stream of net returns beyond this period. A real discount rate of 6.5% is assumed.

Production decisions on CRP, idle, and pasture acres require additional considerations to those made on cropland planted to traditional crops. On CRP acres, it is assumed that existing contracts, upon expiration, can either be renewed under the same conditions that were in effect upon initial enrollment in the program or the acres can be planted to bioenergy crops under a modified contract. This assumption greatly simplifies the analysis by not requiring development of a model to determine re-enrollment decisions for acres currently under contract or to determine acres that may be newly enrolled during CRP sign-ups that occur during the period of analysis. In exchange for being allowed to produce and harvest bioenergy crops on CRP acres, 25% of the current rental rate on the acres is forfeited. Thus, the decision to allocate CRP acres to bioenergy crop production is reduced to a comparison of the net present value of producing bioenergy crops with the net present value of the foregone CRP rental payments.

Cropland acres that are idle or in pasture are assumed to be idled or in pasture for economic reasons—that is, given prices, costs of production, and yields, the most economic use of the land is either to not plant a crop or to dedicate it to pasture. In order to return these acres to production of the major crops or to plant bioenergy crops, the net present value returns of these crops must be higher than the most profitable crop under the baseline assumptions. Furthermore to account for possible inertia to keep the land in its current use and/or the value of pasture land in livestock operations, the model assumes a premium of 10% above the baseline net present returns for idled acres and 15% for pasture acres is required.

## Land Allocation Rules

To avoid corner solutions in the regional linear programming models, POLYSYS contains embedded flexibility constraints that limit the acreage that a given crop can lose or gain each year. To accommodate the addition of bioenergy crops, these allocation rules were modified to the following:

- If the net present value in years t, t-1, and t-2 is positive, the acreage of a crop can increase/decrease by up to 10% of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- If the net present value in years t and t-1 is negative and positive in year t-2, the acreage of a crop can increase/decrease by up to 30% of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- If the net present value in years t, t-1, and t-2 is negative, the acreage of a crop can increase/decrease by up to 50% of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- For crops comprising more than 20% of the total planted acres for all crops in an ASD, acres that can be gained or lost are limited to 20% of the baseline acreage of the crop.
- Idled and pasture acres that can be reallocated to production agricultural are limited to 40 and 25% respectively of the baseline acres in each ASD.
- Bioenergy crops can gain as much acreage as is available from other crops, given the above constraints.
- Once acreage is allocated to bioenergy crops, the acreage remains allocated to the bioenergy crop for the duration of its productive life cycle.

It is assumed that some type of contractual arrangement between farmers and bioenergy crop users exists which limits, for the duration of the bioenergy crop production cycle, the conversion of acres back to traditional crop production once allocated to bioenergy crops. Since the period of analysis for bioenergy crops is the years 2000-2008, which is less than the production cycle of the three bioenergy crops considered, land allocated to bioenergy crops remains in bioenergy crop production until the end period of the analysis.

## Price Expectations

When dealing with traditional crops under a scenario of relative equilibrium, POLYSYS has historically calculated expected future prices using a naïve price expectation hypothesis that utilizes a weighted average of prices in the previous three years. However, the introduction of bioenergy crops offers the possibility of significant shifts in the way agricultural cropland is allocated, which could potentially result in significant impacts on the prices of traditional agricultural crops. Thus POLYSYS has been modified to estimate future expected crop prices using a rational expectations approach.

Rational expectations are premised on the hypothesis that in a given year, farmers will anticipate price changes resulting from significant shifts of acreage from traditional crops to bioenergy crops and will incorporate these price changes into their planting decisions. These changes in expected prices are estimated in POLYSYS through an iterative process. In the first step of the iteration, the supply module in POLYSYS allocates acres to traditional and bioenergy crops using naïve price expectations for traditional crops (i.e., a weighted average of past prices) and assumed market prices for bioenergy crops. The supply of traditional crops resulting from the allocation interacts with the demand module in POLYSYS to estimate the changes in prices for traditional crops. These "new" prices for traditional crops are now used as the prices farmers expect to receive for these crops in the second step of the iteration process. Assuming the "new" market prices for traditional crops and the same prices for bioenergy crops assumed in the first step, the supply module in POLYSYS then re-estimates the acres allocated to traditional and bioenergy crops. These new supply quantities interact with the demand module to once again estimate the "new" market prices for traditional crops. The two step iteration is repeated until the changes in prices for traditional crops between the two iterations are less than a predetermined convergence factor.

Since there are no well-developed markets for the bioenergy crops, their prices are determined exogenously. To keep bioenergy crop prices consistent with each other, the price of switchgrass is used as the numéraire, and the prices of hybrid poplar and willow are adjusted based on their energy content (in Btu per dry ton).

## Modeling Implications

The production and land allocation rules can be summarized in the following mathematical formulation, which indicates that for each time period (*t*) in each POLYSYS region (*r*), acres (*x*) are allocated based on the net present value for each crop (*k*), subject to land availability (X) in each land category (*l*) (cropland in major crops, cropland in CRP, cropland idle, and cropland in pasture), and subject to the upper (*U*) and lower limits (*L*) on the acreage planted to each crop.

$$Max_r^t \quad \sum_l \sum_k x_k^{l,t} NPV_k^{l,t}$$

$$\textit{subject to}:$$

$$\sum_l \sum_k x_{l,k} \leq X_l$$

$$\sum_l \sum_k x_{l,k} \leq U_{l,k}$$

$$\sum_l \sum_k x_{l,k} \geq L_{l,k}$$

The NPV includes any government payments on a per acre basis, such as the CRP rental rate, and is estimated using the price expectation formulation described previously.

# Chapter III: **ESTIMATED IMPACTS OF BIOENERGY CROP PRODUCTION**

A number of alternative scenarios were constructed and estimated, but to facilitate the discussion of the economic feasibility and potential economic impacts of bioenergy crop production on the agricultural sector, the results of just two scenarios are presented. These two scenarios, summarized in Table 3, were chosen because they serve to place boundaries around the discussion.

The wildlife diversity scenario assumes a bioenergy farmgate price (i.e. no transportation costs included) of $30/dry ton for switchgrass, $31.74/dt for willow, and $32.90/dt for hybrid poplar. Because the energy density of the three bioenergy crops differs slightly, an equivalent energy price in $/MBtu results in slightly different $/dry ton prices. The $/MBtu value assumed for all three crops is $1.94). This scenario also assumes that wildlife management practices are employed on CRP acres and that farmers receive 75% of their rental rate in exchange for the right to harvest and sell bioenergy crops.

The production management scenario assumes a bioenergy farmgate price of $2.58/MBtu for each energy crop which is equivalent to $40/dry ton for switchgrass, $42.32/dt for willow, and $43.87/dt for hybrid poplar. This scenario assumes that production management practices are employed on CRP acres and that farmers receive 75% of their current rental rate in exchange for the right to harvest and sell bioenergy crops.

Both scenarios use the 1999 USDA baseline for the eight major crops in the analysis (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice) and the 1999 FAPRI baseline for alfalfa and other hay which are not included in the USDA baseline. CRP baseline acres and location are those prevailing on October 1, 1998. Idle and pasture baseline acres and location are obtained from the 1997 Census of Agriculture and are assumed to be representative of, and consistent with, the baseline information for the major crops.

Bioenergy crop production is assumed to begin in the year 2000, and the largest shift in land is estimated to occur in that year. Annual impacts for the period 2000-2008 are available for each scenario, but to facilitate the presentation of the results, only the results from the year 2008 are presented. Results from 2008 are presented because it is assumed that most of the initial shock resulting from the allocation of land to bioenergy crop production will have occurred by this time and that the agricultural production sector will have settled into a new long-run equilibrium.

Bioenergy crops not only compete with traditional crops for land, but with each other as well. Land is allocated to the bioenergy crops with the greatest average net returns. As discussed in previous sections, switchgrass is relatively the least expensive bioenergy crop to produce, and at similar market prices, switchgrass is relatively more profitable than poplar or willow. As a result, in most ASDs, switchgrass has higher average net returns for each price scenario examined in the analysis and bioenergy crop acres are generally allocated to switchgrass production (see Appendix 4 for detailed description of regional average costs and returns of bioenergy crops).

This does not imply that for any given field or soil type within an ASD, willow or poplar could not be produced more profitably than switchgrass or traditional crops. Rather, the analysis considers only average net present value returns for the entire ASD, given the assumed average yields and typical management practices for each bioenergy crop in each ASD. Variations in average returns

| **Wildlife Management Scenario*** | | **Production Management Scenario*** | |
|---|---|---|---|
| Farmgate Crop Price | $1.94/MBtu | Farmgate Crop Price | $2.58/MBtu |
| • Switchgrass | $30.00/dt | • Switchgrass | $40.00/dt |
| • Willow | $31.74/dt | • Willow | $42.32/dt |
| • Hybrid Poplar | $32.90/dt | • Hybrid Poplar | $43.87/dt |
| Wildlife Management Practices on CRP land | | Production Management Practices on CRP land | |
| • Fewer fertilizer and chemical inputs | | • Standard fertilizer and chemical inputs | |
| • Annual switchgrass harvest is limited to alternating halves each year | | • Annual switchgrass harvest of whole field | |
| Retain 75% CRP rental rate | | Retain 75% CRP rental rate | |

*For complete details on the two management practices see Appendix 3

**Table 3. Comparison between wildlife management scenario and production management scenario**

between ASDs is accounted for in the model, but site specific variations in returns within an ASD are not accounted for in the analysis.

At prices that are 20% higher than switchgrass (in $/MBtu), and keeping production costs and yields fixed, willow achieves a net present value return greater than switchgrass in many ASDs where both can be produced. Similarly, at a $/MBtu price that is 15% higher than switchgrass, poplar is relatively more profitable. Thus, combinations of yields, production costs, and market prices that provide a 15 to 20% differential in net present value returns between short rotation woody crops and switchgrass would result in more acres being allocated to poplar and willow, over switchgrass (on acres for which the relative profitability of bioenergy crops exceeds those of traditional crops). A situation like this happens on CRP acres under the wildlife management scenario. The restrictions placed on the production and harvest of switchgrass relative to that of short rotation woody crops alter the relative profitability enough that significant acres of bioenergy crop production shift from switchgrass production (which occurs on CRP acres under the production management scenario) to hybrid poplar production. Willow, having the least average profitability, still does not enter the solution set in the analysis.

Thus, under the conditions and assumptions used in the analysis, switchgrass dominates the other two bioenergy crops under most scenarios considered. Under selected conditions, acres are also allocated to poplar but not to willow. The remaining discussion of the impacts of bioenergy crops production on the agricultural sector reflects these results.

## Land Use Impacts

Estimated total national acres allocated to bioenergy crops under the two scenarios are presented in Table 4. Under the wildlife management scenario, 19.4 million acres of cropland are planted to bioenergy crops with 10.4 million of those acres (54%) coming from acres that are planted to traditional crops. An estimated 8.2 million CRP acres, 0.2 million idled acres, and 0.5 million pasture acres are converted to bioenergy crop production. For the production management scenario, an estimated 41.9 million acres are planted to bioenergy crops with 23.4 million of those acres coming from acres planted to traditional crops and 12.9 million acres are from converted CRP acres. An estimated 2.1 million idled acres and 3.5 million pasture acres are also converted to bioenergy crop production.

Tables 5 and 6 present the shifts in acres from the major crops and cropland categories that result from the introduction of bioenergy crops. Total cropland acres planted increase from the baseline 325.4 million to 335.9 million under the wildlife management scenario and to 346.8 million acres under the production management scenario. Increased acreage comes almost exclusively from CRP acres in the wildlife management scenario and from CRP, idled, and pasture acres in the production management scenario. Many traditional crops lose acres as a result of bioenergy crop production, but gain acres from production on idled and pasture acres. This effect occurs because the shift in acres resulting from the introduction of bioenergy crops results in lower production of traditional crops and thus higher traditional crop prices. The higher prices provide sufficient incentive to return some idled and pasture acres

| Units in Million Acres | Wildlife Management Scenario | | | | |
|---|---|---|---|---|---|
| | **All Cropland** | **Major Crops** | **CRP** | **Idle** | **Pasture** |
| **Switchgrass** | 12.32 | 10.44 | 1.1 | 0.23 | 0.55 |
| **Hybrid Poplar** | 7.10 | 0 | 7.1 | 0 | 0 |
| **Willows** | 0 | 0 | 0 | 0 | 0 |
| **All Bioenergy** | 19.42 | 10.44 | 8.20 | 0.23 | 0.55 |
| Units in Million Acres | **Production Management Scenario** | | | | |
| | **All Cropland** | **Major Crops** | **CRP** | **Idle** | **Pasture** |
| **Switchgrass** | 41.87 | 23.37 | 12.91 | 2.09 | 3.49 |
| **Hybrid Poplar** | 0 | 0 | 0 | 0 | 0 |
| **Willows** | 0 | 0 | 0 | 0 | 0 |
| **All Bioenergy** | 41.87 | 23.37 | 12.91 | 2.09 | 3.49 |

**Table 4. Plantings of bioenergy crops, 2008**

| Million Acres | USDA baseline (Feb. 1999) | WILDLIFE MANAGEMENT SCENARIO | | | |
|---|---|---|---|---|---|
| | 1999 Acres | Effect on cropland in major crops | Acreage gained from idle & pasture | Net Change | 2008 Acres |
| **Corn** | 82.0 | -2.2 | 0.8 | -1.4 | 80.6 |
| **Sorghum** | 10.6 | 0.0 | 0.0 | 0.0 | 10.6 |
| **Oats** | 4.7 | -0.1 | 0.0 | -0.1 | 4.6 |
| **Barley** | 7.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| **Wheat** | 73.1 | -1.8 | 0.4 | -1.4 | 71.7 |
| **Soybeans** | 71.8 | -2.0 | 0.1 | -1.9 | 69.9 |
| **Cotton** | 12.8 | -0.8 | 0.3 | -0.5 | 12.3 |
| **Rice** | 3.2 | -0.1 | 0.0 | -0.1 | 3.1 |
| **Alfalfa** | 27.1 | -1.0 | 0.0 | -1.0 | 26.1 |
| **Other Hay** | 33.1 | -2.5 | 0.0 | -2.5 | 30.6 |
| **Bioenergy** | 0.0 | 18.6 | 0.8 | 19.4 | 19.4 |
| **Total CRP** | 29.8 | -8.2 | 0.0 | -8.2 | 21.6 |
| **Total Planted** | 325.4 | 8.2 | 2.3 | 10.5 | 335.9 |
| **Idle and Pasture** | 79.3 | -2.3 | 0.0 | -2.3 | 77.0 |

**Table 5. Cropland changes due to introduction of bioenergy crops, 2008**
**Wildlife management scenario**

| Million Acres | USDA baseline (Feb. 1999) | PRODUCTION MANAGEMENT SCENARIO | | | |
|---|---|---|---|---|---|
| | 1999 Acres | Effect on cropland in major crops | Acreage gained from idle & pasture | Net Change | 2008 Acres |
| **Corn** | 82.0 | -4.7 | 1.0 | -3.7 | 78.3 |
| **Sorghum** | 10.6 | -0.4 | 0.0 | -0.4 | 10.2 |
| **Oats** | 4.7 | -0.2 | 0.1 | -0.1 | 4.6 |
| **Barley** | 7.0 | 0.0 | 0.0 | 0.0 | 7.0 |
| **Wheat** | 73.1 | -7.4 | 1.2 | -6.2 | 66.9 |
| **Soybeans** | 71.8 | -3.5 | 0.1 | -3.4 | 68.4 |
| **Cotton** | 12.8 | -1.2 | 0.5 | -0.7 | 12.1 |
| **Rice** | 3.2 | -0.1 | 0.0 | -0.1 | 3.1 |
| **Alfalfa** | 27.1 | -2.2 | 0.0 | -2.2 | 24.9 |
| **Other Hay** | 33.1 | -3.7 | 0.0 | -3.7 | 29.4 |
| **Bioenergy** | 0.0 | 41.2 | 0.7 | 41.9 | 41.9 |
| **Total CRP** | 29.8 | -12.9 | 0.0 | -12.9 | 16.9 |
| **Total Planted** | 325.4 | 17.8 | 3.6 | 21.4 | 346.8 |
| **Idle or Pasture** | 79.3 | -8.5 | 0.0 | -8.5 | 70.8 |

**Table 6. Cropland changes due to introduction of bioenergy crops, 2008**
**Production management scenario**

| Crop | Million Acres | |
|---|---|---|
| | Bioenergy Crop Management Scenario | |
| | Wildlife | Production |
| Corn | 0.237 | 0.277 |
| Sorghum | 0.003 | 0.000 |
| Oats | 0.005 | 0.000 |
| Wheat | 0.129 | 0.301 |
| Soybeans | 0.034 | 0.031 |
| Cotton | 0.249 | 0.454 |
| Bioenergy | 0.228 | 2.093 |
| Total all crops | 0.877 | 3.156 |

**Table 7. Idle cropland brought back into crop production, 2008**

| Crop | Million Acres | |
|---|---|---|
| | Bioenergy Crop Management Scenario | |
| | Wildlife | Production33 |
| Corn | 0.595 | 0.712 |
| Wheat | 0.217 | 0.921 |
| Soybeans | 0.081 | 0.065 |
| Bioenergy | 0.548 | 3.485 |
| Total all crops | 1.441 | 5.183 |

**Table 8. Cropland in pasture brought back into crop production, 2008**

| Crop | Acres |
|---|---|
| Corn | -965,908 |
| Oats | + 58,569 |
| Soybeans | +904,671 |
| Bioenergy | + 2,667 |

**Table 9. Changes in traditional crop production in Iowa resulting from the national introduction of bioenergy crops - production management scenario.**

to traditional crop production. For example, under the production management scenario, corn loses 4.7 million acres as a result of bioenergy crop production, but higher corn prices result in the conversion of 1 million idled and pasture acres to corn production resulting in a net loss of 3.7 million corn acres.

Tables 7 and 8 detail the acres shifted to traditional crops and to bioenergy crops from idle and pasture acres under the two scenarios. In addition to changes in total crop acres allocated to each traditional crop on a national level, shifts of acres among traditional crops at a regional level may also occur. As an example, Iowa loses nearly 1 million acres of corn production (Table 9) under the production management scenario. However, less than 3,000 of these acres are shifted to bioenergy crop production. Rather, the changes in relative prices of traditional crops cause a reallocation of corn acres in Iowa to increased soybean production with some additional acres also allocated to oats production. Similar shifts in the allocation of traditional crop acres occur in other states as well, as the relative prices of traditional crops change as a result of the introduction of bioenergy crops.

As discussed previously, bioenergy crops compete for acreage not only with traditional crops, but with each other as well. Acreage from each ASD is allocated to each crop based on average NPV profit given the assumed yields, production costs, and land allocation rules described previously. In nearly every ASD, growing switchgrass is relatively more profitable than hybrid poplar which is in turn relatively more profitable than willow. As a result, switchgrass dominates the other two bioenergy crops and nearly all (99%) of the acres in traditional crops, idled, or in pasture that are shifted to bioenergy crop production are shifted to switchgrass production under both scenarios. In a few ASDs, hybrid poplar is the most profitable bioenergy crop and acres are allocated to it in these ASDs. Willow, being the least profitable of the three bioenergy crops cannot compete for acres with the other two bioenergy crops and no acres are allocated to willow in the analysis.

The bioenergy crop produced on CRP acres depends on the scenario assumed (Table 10). The wildlife management scenario places substantial penalties on switchgrass in terms of yields and production costs relative to those of hybrid poplar and willow. As a result, for any given bioenergy crop price, the relative profitability of hybrid poplar exceeds that of switchgrass and willow on a substantial portion of the CRP acres allocated to bioenergy crops. On the remaining CRP acres allocated to bioenergy crops under the wildlife scenario, switchgrass is relatively more profitable than willow, and the acres are allocated to switchgrass. Under the production management scenario, switchgrass is the relatively more profitable crop and the CRP acres are allocated to it. The results suggest that the interaction between the environmental and economic benefits will require further delineation of management practices that provide a high level of both benefits.

Figures 6-12 present the regional distribution of bioenergy crop production by cropland type for the two sce-

| Crop | Million Acres | |
|---|---|---|
| | Wildlife Management Scenario | Production Management Scenario |
| **Switchgrass** | 1.099 | 12.913 |
| **Poplar** | 7.097 | 0 |
| **All bioenergy** | 8.196 | 12.913 |
| **Bioenergy potential** | 16.925 | 16.925 |
| **Available CRP for bioenergy** | 22.608 | 22.608 |
| **All CRP through October 1998** | 29.788 | 29.788 |

**Table 10. CRP plantings, 2008**

narios. Figure 6 presents the location and range of acreage of switchgrass production on all cropland acres (combined acres in crops, idled, in pasture, and in CRP) and Figures 7 and 8 present the acres and location of switchgrass and hybrid poplar respectively on CRP acres under the wildlife management scenario. Under this scenario, switchgrass production on CRP acres occurs primarily in the southeastern United States. Hybrid poplar production on CRP acres occurs predominantly in the Midwest and Lake States region. Figure 9 presents the location (in acres) of switchgrass production on all cropland acres and Figure 10 presents the location of switchgrass production on CRP acres under the production management scenario. Under this scenario, switchgrass production occurs throughout the United States in nearly every ASD where production is permitted in the analysis. The highest concentration of acres occurs in the Northern and Southern Plains regions.

Figures 11 and 12 present the location of bioenergy crop production (in dry tons) under the two scenarios. Table 11 contains the quantities (in dry tons) of bioenergy

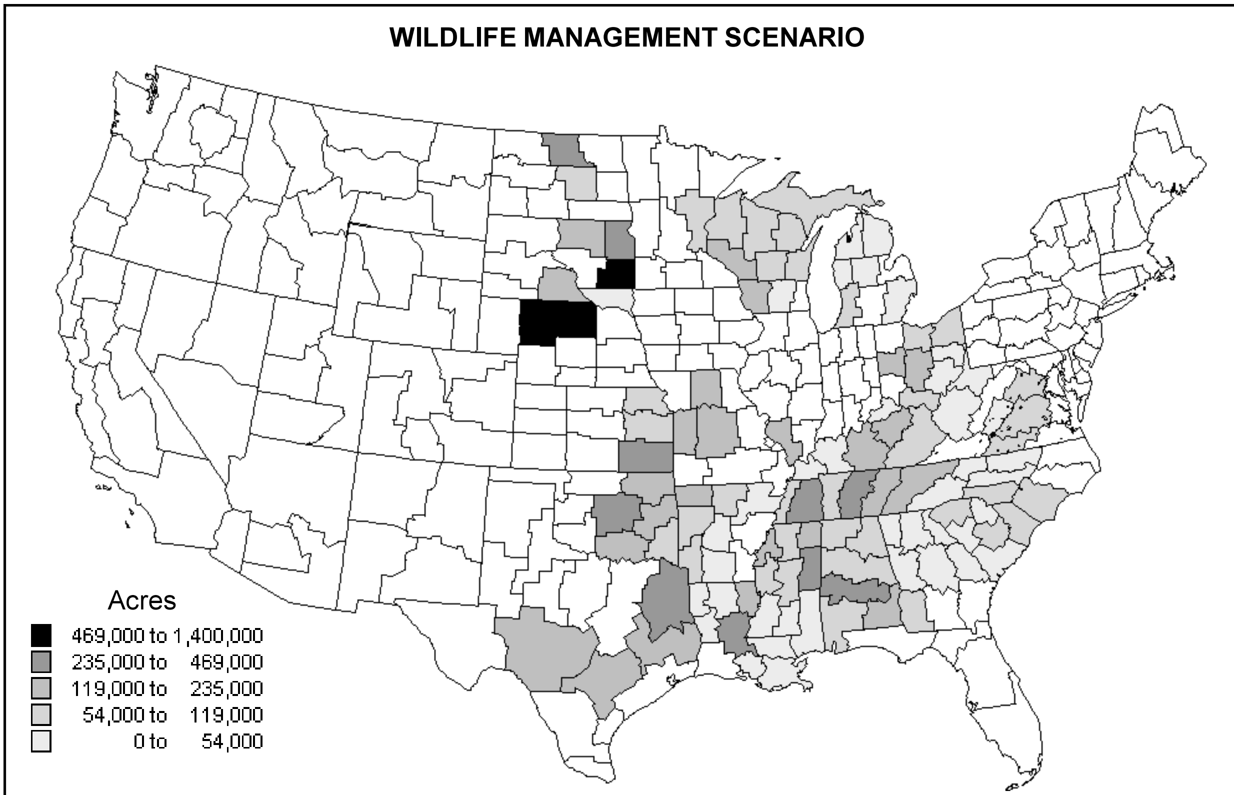


**Figure 6. Switchgrass plantings on all cropland, 2008**

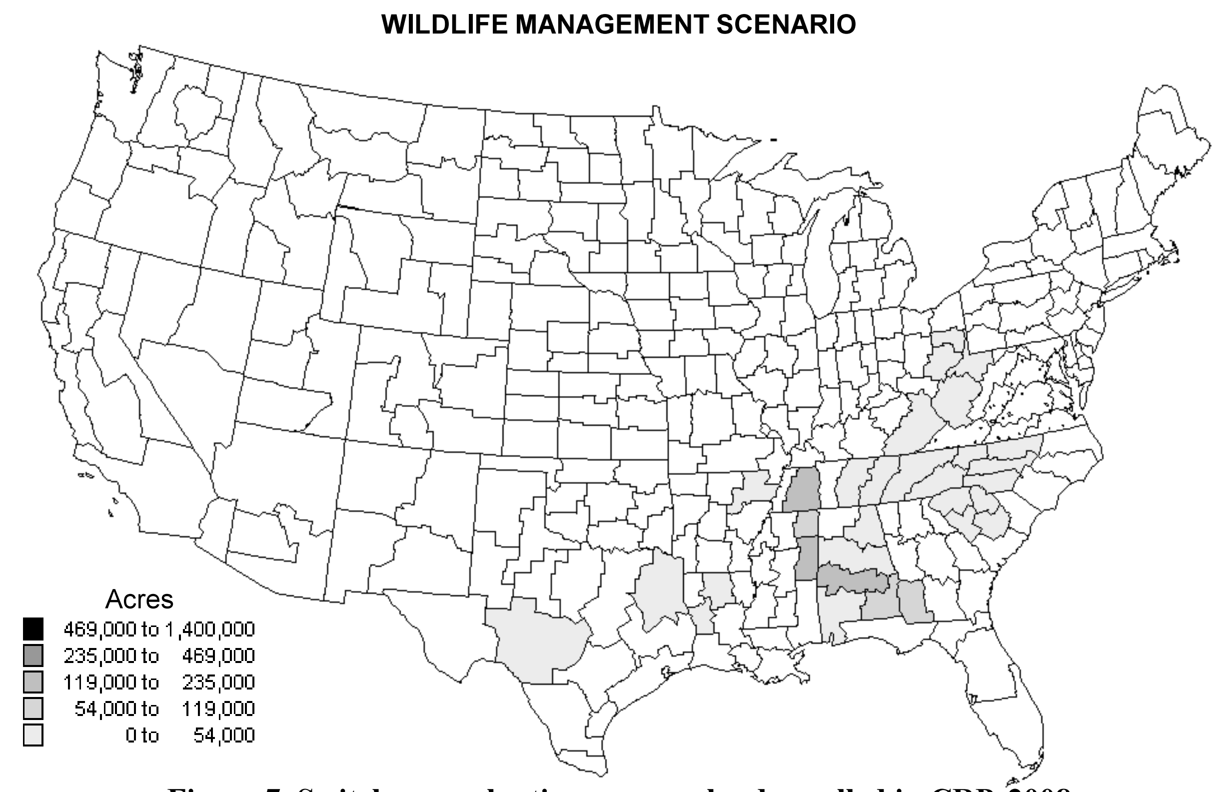


**Figure 7. Switchgrass plantings on cropland enrolled in CRP, 2008**

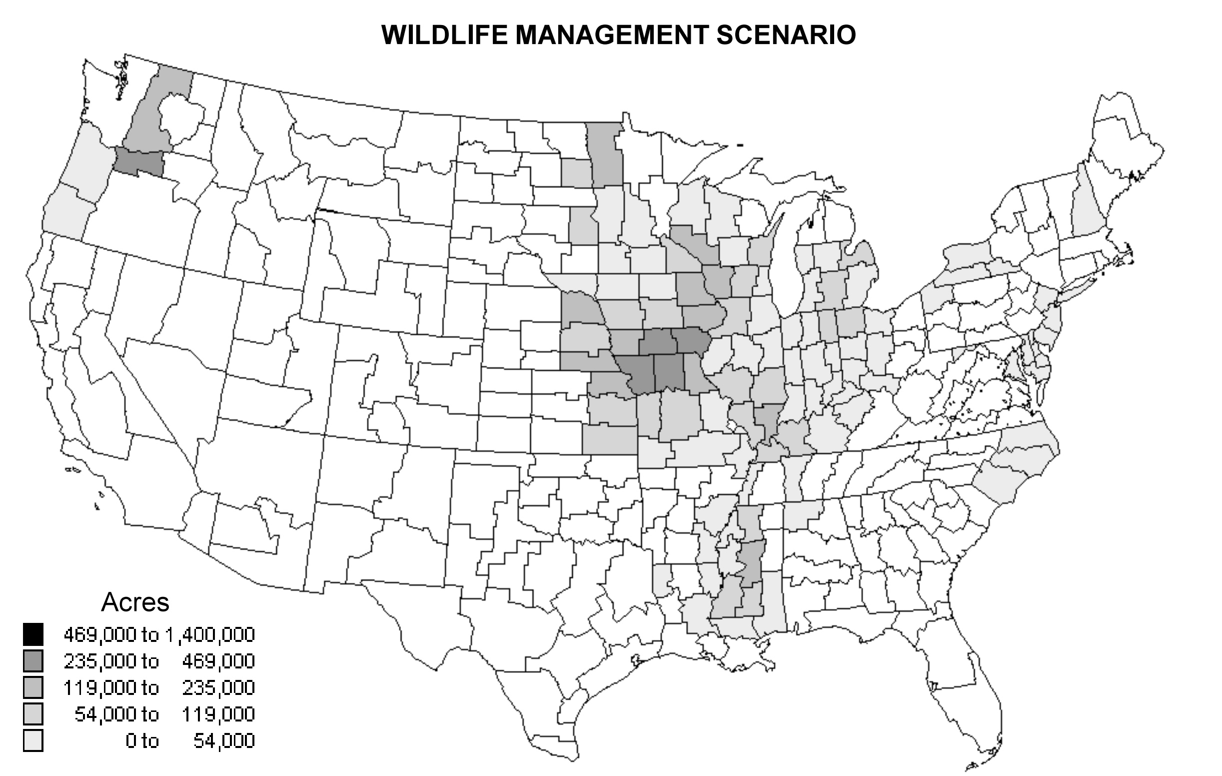


**Figure 8. Poplar plantings on cropland enrolled in CRP, 2008**

**PRODUCTION MANAGEMENT SCENARIO**

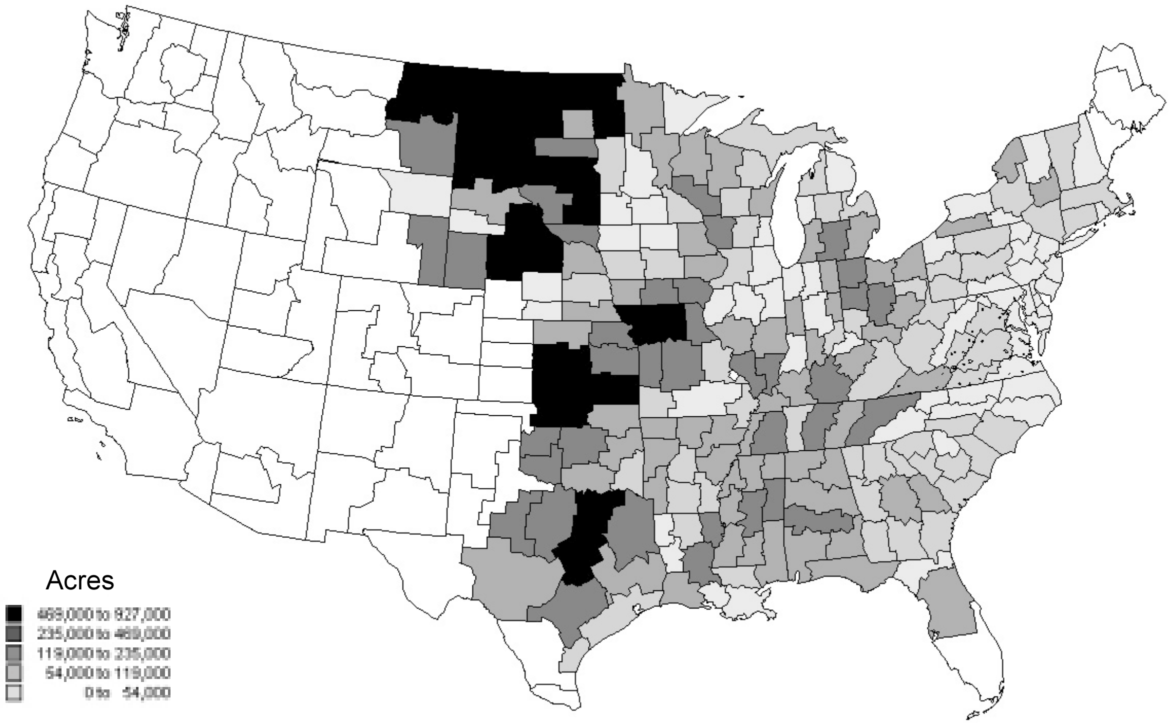


**Figure 9. Switchgrass plantings on all cropland, 2008**

**PRODUCTION MANAGEMENT SCENARIO**

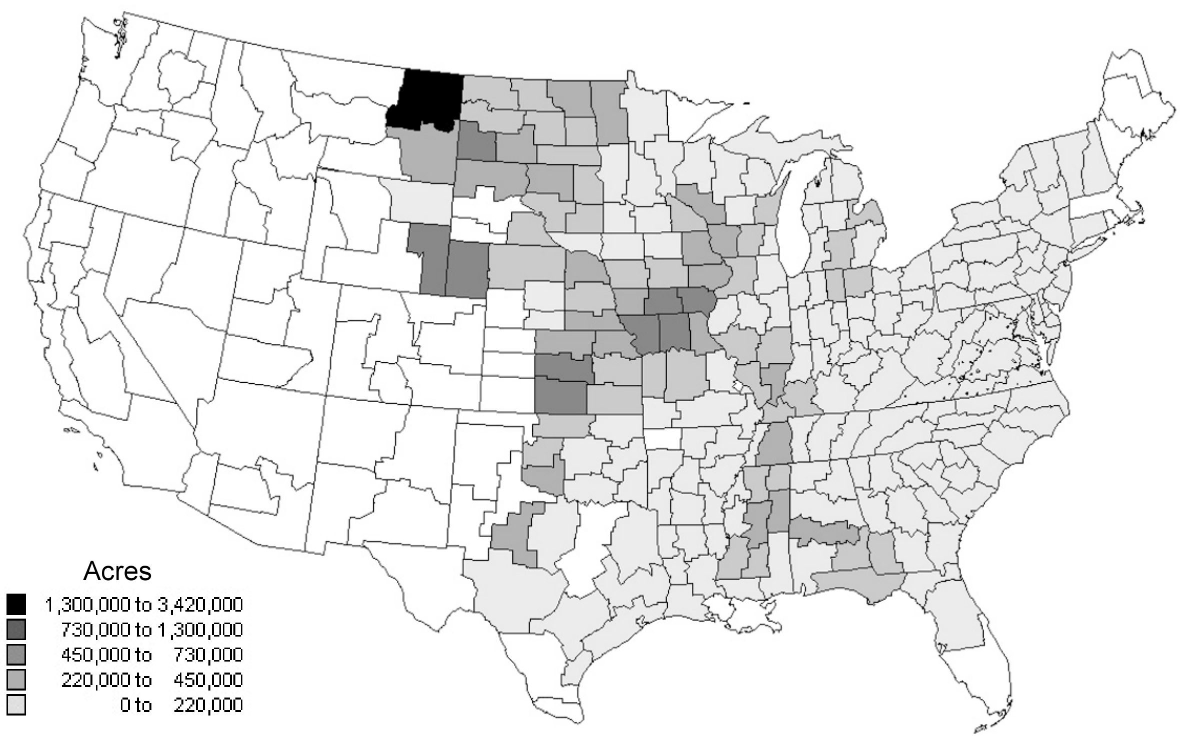


**Figure 10. Switchgrass plantings on cropland enrolled in CRP**

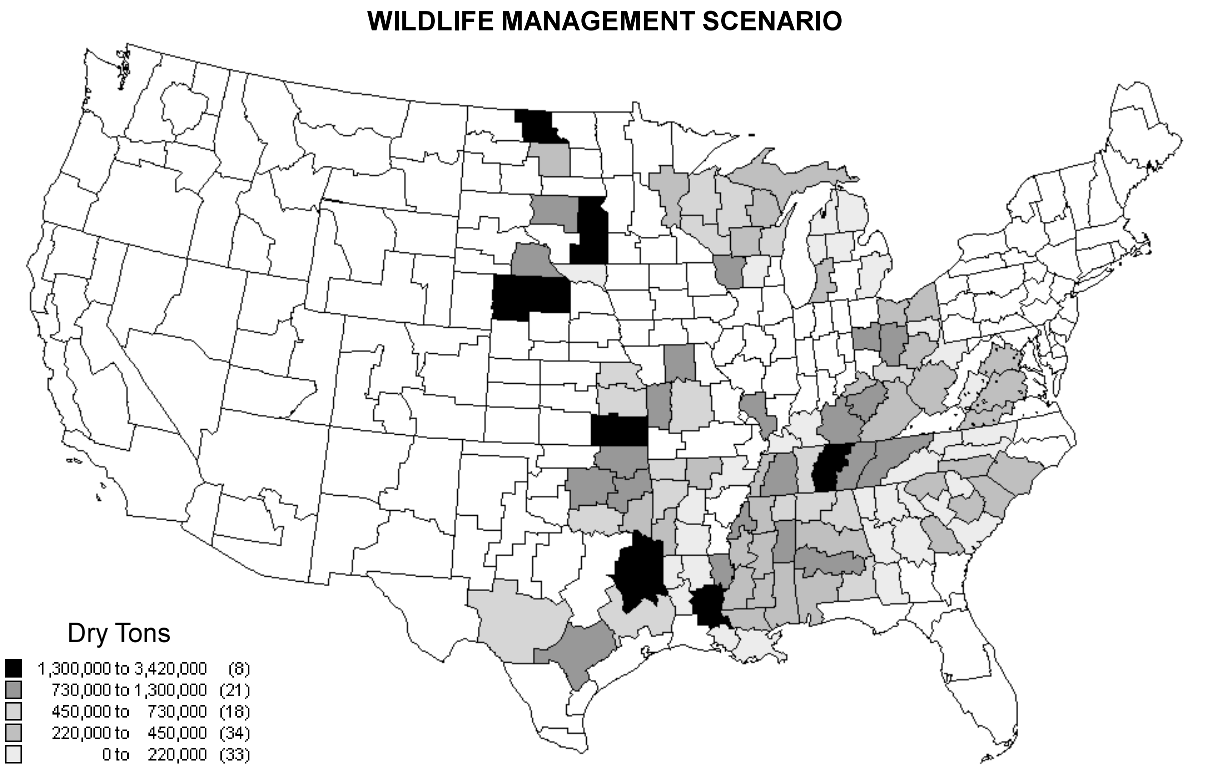


**Figure 11. Production of biomass by ASD, 2008**

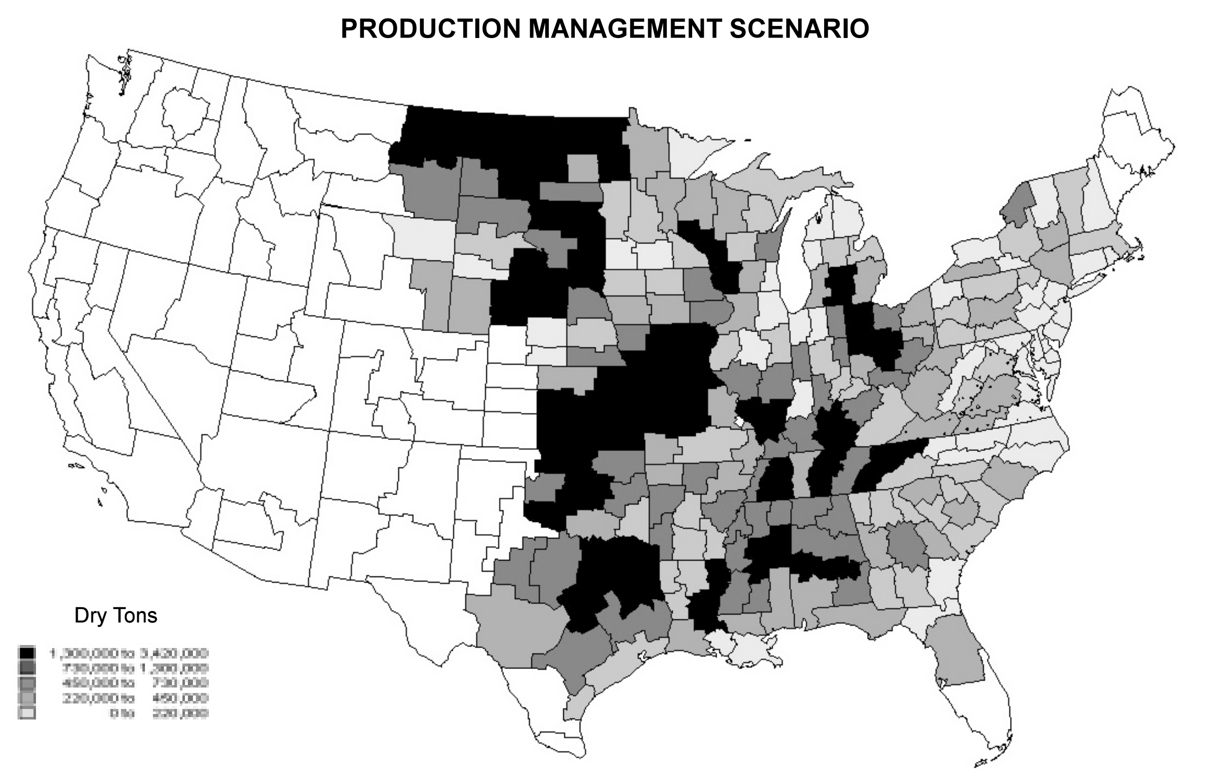


**Figure 12. Production of biomass by ASD, 2008**

| | Wildlife Management Scenario | Production Management Scenario |
|---|---|---|
| **State** | **Production in million dry tons** | |
| Alabama | 3.1 | 6.6 |
| Arkansas | 2.2 | 5.5 |
| Connecticut | 0.0 | 0.2 |
| Delaware | 0.0 | 0.0* |
| Florida | 0.0 | 1.3 |
| Georgia | 1.3 | 4.0 |
| Illinois | 0.8 | 7.7 |
| Indiana | 0.0 | 5.0 |
| Iowa | 0.0 | 8.3 |
| Kansas | 2.9 | 11.4 |
| Kentucky | 3.0 | 5.1 |
| Louisiana | 3.7 | 5.8 |
| Maryland | 0.0 | 0.3 |
| Massachusetts | 0.0 | 0.2 |
| Michigan | 1.2 | 4.2 |
| Minnesota | 0.4 | 5.8 |
| Mississippi | 4.3 | 9.3 |
| Missouri | 2.5 | 12.8 |
| Montana | 0.0 | 2.8 |
| Nebraska | 1.9 | 5.2 |
| New Hampshire | 0.0 | 0.2 |
| New Jersey | 0.0 | 0.1 |
| New York | 0.0 | 3.4 |
| North Carolina | 0.6 | 1.6 |
| North Dakota | 1.9 | 16.8 |
| Ohio | 3.8 | 9.7 |
| Oklahoma | 3.6 | 8.1 |
| Pennsylvania | 0.0 | 2.3 |
| Rhode Island | 0.0 | 0.0* |
| South Carolina | 1.3 | 2.4 |
| South Dakota | 5.6 | 12.8 |
| Tennessee | 6.5 | 9.4 |
| Texas | 4.5 | 9.1 |
| Vermont | 0.0 | 0.3 |
| Virginia | 1.3 | 2.6 |
| West Virginia | 0.3 | 1.2 |
| Wisconsin | 3.6 | 6.1 |
| Wyoming | 0.0 | 0.5 |
| Total | 60.5 | 188.1 |

**Note:** The production of bioenergy crops is not assumed in Arizona, California, Idaho, Nevada, New Mexico, and Utah. Although production occurs in Oregon and Washington, harvest has not yet occurred by 2008. Addition of annualized production of poplar under Scenario 1 adds an additional 35.5 million dry tons with production occurring in Oregon and Washington.

* Delaware 0.03; Rhode Island 0.005

**Table 11. Production of switchgrass by state, 2008**
**Comparison between the wildlife management scenario and the production management scenario**

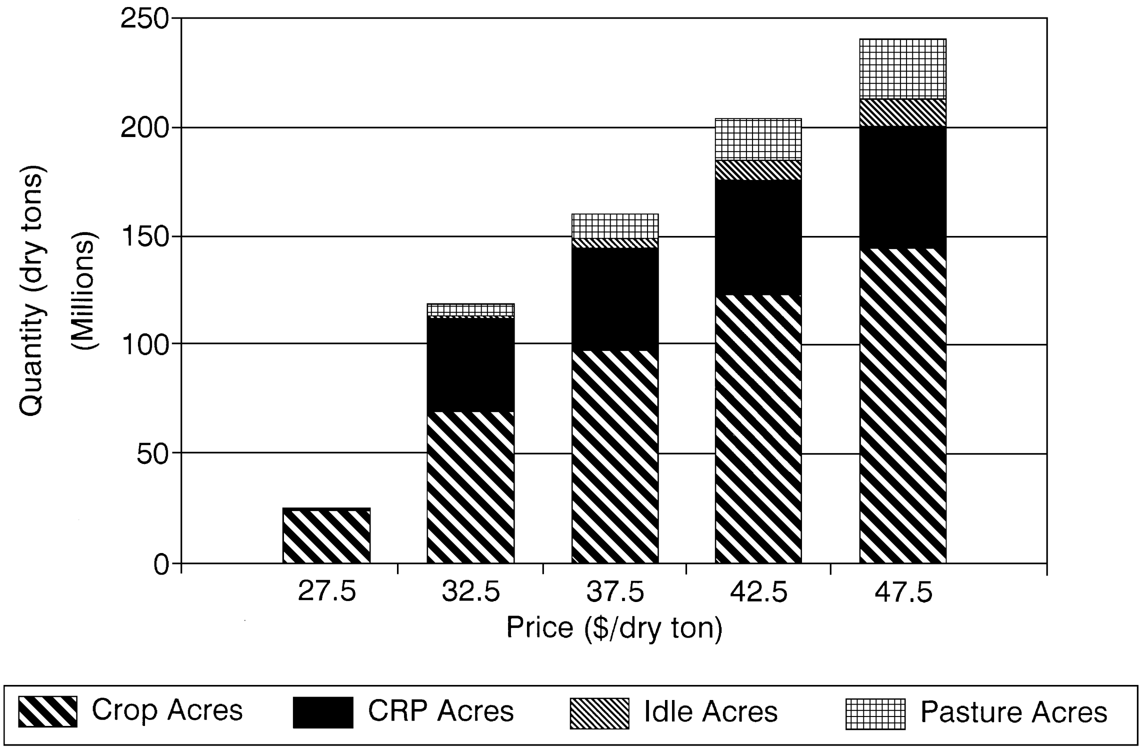


**Figure 13. Biomass production at selected prices by cropland type and assuming the production management scenario on CRP acres (million dt)**

crops available by state under the two scenarios. Total national production in the year 2008 under the wildlife management scenario is an estimated 60.5 million dry tons annually. While most of the poplar is not harvested until after 2008, its contribution can be annualized to provide an equivalent annual amount of 35.5 million dry tons; for a total of 96 million tons of feedstock. Under the production management scenario, an estimated 188 million dry tons could be produced annually. This production would be generated exclusively from switchgrass.

For convenience, we present detailed results of the analysis for two price scenarios only. It is useful however to elucidate the potential national supply by cropland type (cropland in traditional crops, idle, pasture and CRP) for different price scenarios. Figure 13 presents these estimates for selected bioenergy crop prices assuming the production management scenario for bioenergy crops on CRP acres.

## Price Impacts

The shift of cropland from traditional crops to bioenergy crops results in higher prices for traditional crops. The impact on traditional crop prices is a function of the acreage shifted to bioenergy crops, as well as the elasticity of supply and demand parameters for each crop. Price impacts for the two scenarios are presented in Table 12. Traditional crop prices increase by an estimated 4 to 9% under the wildlife management scenario, depending on crop and by an estimated 9 to 14% under the production management scenario. Cotton and rice experience the largest price increases under the wildlife management scenario while cotton and sorghum show the largest increases under the production management scenario. It should be noted that the higher estimated prices for the major crops, except wheat, are within the range of historical market prices experienced by these crops over the last five years. For example, corn prices have range between $1.95/bu and $3.24/bu. Because POLYSYS calculates the price as changes from the baseline price, the level of the final prices is highly influenced by the price level assumed in the baseline. It should also be noted that POLYSYS is not able to estimate price changes for alfalfa and other hay crops that are generally determined locally rather than at a national level.

## Net Farm Income Impacts

The overall impact of bioenergy crop production on agriculture is summarized by changes in net farm income.

| Crop | Baseline Price | Bioenergy Crop Management Scenario | | | | | |
|---|---|---|---|---|---|---|---|
| | | Value | | Difference | | | |
| | | Wildlife | Production | Wildlife | | Production | |
| Corn/bu. | $2.55 | 2.65 | 2.79 | $0.10 | 4% | $0.24 | 9% |
| Sorghum/bu. | 2.44 | 2.57 | 2.77 | 0.13 | 5% | 0.33 | 14% |
| **Oats/bu.** | **1.50** | **1.58** | **1.67** | **0.08** | **5%** | **0.17** | **11%** |
| **Barley/bu.** | **2.35** | **2.43** | **2.55** | **0.08** | **3%** | **0.20** | **9%** |
| Wheat/bu. | 4.25 | 4.40 | 4.74 | 0.15 | 4% | 0.49 | 12% |
| Soybeans/bu. | 6.10 | 6.42 | 6.71 | 0.32 | 5% | 0.61 | 10% |
| **Cotton/cwt.** | **0.68** | **0.74** | **0.77** | **0.06** | **9%** | **0.09** | **13%** |
| **Rice/cwt.** | **10.37** | **11.23** | **11.37** | **0.86** | **8%** | **1.00** | **10%** |

**Table 12. Price changes for major crops in 2008**

| | Billions of $ | | |
|---|---|---|---|
| | USDA Baseline (Feb. 1999) | Wildlife management scenario | Production management scenario |
| **Crops & Livestock** | 50.5 | 52.6 | 54.2 |
| **Bioenergy Crops** | 0 | 0.7 | 2.3 |
| **Total Net Farm Income** | 50.5 | 53.3 | 56.5 |

**Table 13. Changes in net farm income, 2008**

To account for the contribution of bioenergy crops to net farm income, the net present value resulting from the production of biomass is expressed in terms of an annuity and added to the farm income measures used for the major crops and livestock sector. Again, POLYSYS is not able to estimate changes in alfalfa and other hay prices which are generally determined locally rather than nationally. Alfalfa and other hay prices are likely to increase generating extra income for these producers and consequently cause losses for livestock producers who feed hay and alfalfa to their cattle. The net effects, which could be negative, neutral or positive, have not been accounted for in the income estimates.

The changes in the annual net farm income generated in the year 2008 under the two scenarios are shown in Table 13. Under the wildlife management scenario, a gain of $2.8 billion is projected with bioenergy crops accounting for $700 million of that total and the rest resulting from higher traditional crop prices. Under the production management scenario, a gain of $6.0 billion is projected with bioenergy crops accounting for $2.3 billion of that total and the rest resulting from higher traditional crop prices.

Table 14 presents the change in estimated net farm income resulting directly from the introduction of bioenergy crop production by state for the two scenarios. Under the wildlife management scenario, the gains in income generated by the production of bioenergy crops are highest in the Midwest, Northern Plains, Southeast, and Delta regions, although gains are also experienced in the Southern Plains and New England regions. Under the higher price scenario, North and South Dakota in particular experience significant income gains from bioenergy crop production. Bioenergy crops could potentially provide an effective alternative for these wheat-dependent states. States with a relatively larger agricultural base also benefit the most from the price increase experienced by the major crops.

| | Wildlife management scenario | Production management scenario |
|---|---|---|
| **State** | **Million dollars** | |
| Alabama | 22 | 89 |
| Arkansas | 10 | 63 |
| Connecticut | 0 | 1 |
| Delaware | 0 | 0 |
| Florida | 0 | 11 |
| Georgia | 3 | 40 |
| Illinois | 53 | 128 |
| Indiana | 19 | 76 |
| Iowa | 112 | 184 |
| Kansas | 26 | 127 |
| Kentucky | 27 | 75 |
| Louisiana | 20 | 76 |
| Maryland | 1 | 3 |
| Massachusetts | 0 | 2 |
| Michigan | 17 | 55 |
| Minnesota | 16 | 58 |
| Mississippi | 36 | 131 |
| Missouri | 88 | 214 |
| Montana | 0 | 19 |
| Nebraska | 32 | 83 |
| New Hampshire | 0 | 1 |
| New Jersey | 0 | 1 |
| New York | 1 | 25 |
| North Carolina | 4 | 21 |
| North Dakota | 1 | 137 |
| Ohio | 32 | 128 |
| Oklahoma | 7 | 55 |
| Oregon | 9 | 0 |
| Pennsylvania | 0 | 22 |
| Rhode Island | 0 | 0 |
| South Carolina | 7 | 32 |
| South Dakota | 20 | 137 |
| Tennessee | 37 | 129 |
| Texas | 16 | 75 |
| Vermont | 0 | 2 |
| Virginia | 2 | 27 |
| Washington | 6 | 0 |
| West Virginia | 1 | 12 |
| Wisconsin | 41 | 87 |
| Wyoming | 0 | 5 |
| Total | 666 | 2,331 |

**Note:** The production of bioenergy crops is not assumed in Arizona, California, Idaho, Nevada, New Mexico, and Utah.

**Table 14. Changes in net farm income by state, 2008**
**Comparison between the wildlife management scenario and the production management scenario**

| | Wildlife management scenario | | Production management scenario | |
|---|---|---|---|---|
| | Switchgrass | SRWC* | Switchgrass | SRWC* |
| **Million Acres** | 12.3 | 7.1 | 41.9 | 0 |
| **Million Dry tons** | 60.5 | 35.5 | 188.1 | 0 |
| **Quads** | 0.94 | 0.60 | 2.92 | 0 |
| **Billion Gallons of ethanol** | 5.36 | 3.15 | 16.67 | 0 |
| **Million Barrels of oil displaced** | 81.2 | 47.7 | 252.4 | 0 |
| **MW electricity capacity** | 14,119 | 9.086 | 43,897 | 0 |
| **Percent of electricity capacity** | 1.51 | 0.97 | 4.67 | 0 |
| **Billion kWh electricity (gasifier combined cycle)** | 98.9 | 63.7 | 307.6 | 0 |
| **Percent of electricity supplied** | 2.3 | 1.5 | 7.3 | 0 |

* SWRC - Short Rotation Woody Crop (poplar and willow)

Notes: Energy content of energy crops assumes 15.5 MBtu/dt for switchgrass and 17.) MBtu/dt for hybrid poplar.
Ethanol conversion rate is assumed to be 88.8 gallons/dt.
Oil displaced does not subtract fuel used in crop production and conversion.
Electricity estimates assume gasifier combined cycle with 36% conversion efficiency and 80% operating rate.
Electricity capacity and supply taken from DOE energy Information Administration, *Annual Energy Outlook '99* reference case for the year 2008.

**Table 15. Annual energy production equivalents for bioenergy crops, 2008**

## Energy Supply Implications

Bioenergy crops are being developed as feedstocks for energy or biobased products. Table 15 presents the energy equivalents that could be obtained from bioenergy crop production under the two scenarios. Under the wildlife management scenario, the 96 million dry tons of biomass (60.5 million tons of switchgrass and an additional 35.5 millions tons from the annualized production of poplar that are harvested starting in 2009) produced is equivalent to 1.54 Quads of primary energy. Given current conversion efficiencies, this quantity could be used to produce 8.5 billion gallons of ethanol and displace 129 million barrels of oil annually if used as a transportation fuel in place of gasoline. Current annual fuel ethanol production from corn is about 1.4 billion gallons. Alternatively, this quantity of biomass could be used to produce 163 billion kilowatt hours of electricity (assuming a gasifier combined cycle technology) which is equivalent to about 3.8% of the electricity currently produced in the United States.

Under the production management scenario, annual bioenergy crop production of 188.1 million tons is equivalent to 2.92 Quads of primary energy. Given current conversion efficiencies, it could be used to produce 16.7 billion gallons of ethanol and displace 252 million barrels of oil each year. Alternatively, that quantity of biomass could be used to produce 308 billion kilowatt hours of electricity which is equivalent to about 7.3% of the electricity currently produced in the United States.

# Chapter 4: **SUMMARY AND CONCLUSIONS**

The widespread introduction of bioenergy crops to agriculture could have significant impacts for the agricultural sector. Substantial cropland acres (up to 42 million acres at a switchgrass price of $40/dt) could be profitably shifted to the production of bioenergy crops under the price and management scenarios analyzed in this study. This level of production would make bioenergy crops the fourth largest crop produced in the U.S., in terms of total acres, behind corn, wheat, and soybeans.

Net farm income is estimated to increase in the year 2008 by $2.8 and $6.0 billion under the two scenarios presented. In recent years, traditional crop prices have been low. In order to maintain farm income, the federal government has made direct payments to farmers. These direct payments equaled $12.2 billion in 1998 and $22.7 billion in 1999 and are projected to be $17 billion for 2000 (USDA, 2000). Bioenergy crops offer a potential new production activity that could have a positive impact on farm income.

Increased farm income is a result of the value of the bioenergy crop production itself, as well as an increase over projected baseline prices for traditional crops. Traditional crop prices are estimated to increase from 3% to 14% depending on the traditional crop and the bioenergy crop scenario analyzed. Estimated prices are well within the range of the historic variability of traditional crop prices. For example, under the production management scenario ($40/dt price for switchgrass), the corn price is projected to increase from a baseline price of $2.55/bu to $2.79/bu, a 9% increase. Over the past five years, market prices for corn have ranged from $1.95/bu to $3.24/bu (USDA, April, 1999). During this same time, food prices have remained stable, generally averaging less than a 3 percent increase per year (Elitzak).

The analysis also indicates that CRP acres could become a significant source of biomass crops. Clearly, criteria to determine suitable CRP acres and appropriate bioenergy crop management practices must be developed before CRP acres can be used for bioenergy crop production. However, the analysis of the two management practices examined suggests substantial economic potential to use CRP program acreage for bioenergy crop production. The environmental ramifications of various management practices must be verified to ensure that there is not a substantial loss of environmental benefits resulting from the production of bioenergy crops on CRP acres. Research is ongoing to determine the implications of bioenergy crop production on environmental parameters such as biodiversity and soil and water quality (see for example the 1998 edition of Biomass and Bioenergy, volume 14, number 4 for several articles. Also see Tolbert and Wright, 1998; Christian et al, 1997; Christian, 1997; Hanowski et al, 1997; Schiller et al, 2000; Ma et al, 2000, Tolbert et al, 1999; and Perry et al, 2000 among other studies).

Currently, about 2.6 Quads ($10^{15}$ Btu) of the primary energy used in the industrial sector in the U.S. comes from biomass resources (USDOE, 1999). President Clinton, in an Executive Order signed August 12, 1999 called for a threefold increase in the use of bioenergy and biobased products. Bioenergy crops could play a significant role in achieving that goal. Under the production management scenario, an estimated 188 million dry tons of biomass could be produced. This quantity is equivalent to 2.92 Quads of primary energy. If used to produce ethanol, production would increase nearly 1,100% over the current ethanol production level. Alternatively, 188 million dry tons of biomass could be used to produce nearly 7.3% of the electricity currently produced in the U.S.

Interpretation of the results should consider the limitations to the analysis. For example, in the analysis, acres are allocated based on relative average profitability for an entire ASD. Variations within an ASD are not considered. Thus while the average profitability of switchgrass may be greater than the average profitability of hybrid poplar and willow in most ASDs, there may be some acres within any given ASD for which hybrid poplar or willow are relatively more profitable than switchgrass. These situations are not captured by the analysis. As a result, nearly all of the acres allocated to bioenergy crop production are allocated to switchgrass. Additionally the analysis considers only the time frame of 1999-2008. Improvements in yields and production technologies are occurring for both bioenergy crops and traditional crops.

The analysis is also limited by the inability of the model to estimate price changes for alfalfa and hay. Thus, there may be some income losses in the livestock sector not accounted for in the analysis and also corresponding gains in the production of hay and alfalfa that have not been accounted for either.

Additionally, the analysis is a supply side analysis only. It is beyond the scope of this project to analyze the infrastructure and prices needed to make bioenergy a reality. Farmgate prices of $40/dt are higher than mid-1999 market prices for fossil fuels. In addition, it should be noted that fossil fuel market prices do not fully reflect many of the environmental and social externalities associated with their use. This point is particularly significant in light of growing concerns over global climate change.

# REFERENCES


Christian, D.P., P.T. Collins, J.M. Hanowski, G.J. Niemi. 1997. Bird and small mammal use of short-rotation hybrid poplar plantations. *Journal of. Wildlife Management*. 61(1):171-182.

Christian, D.P. 1997. Wintertime use of hybrid poplar plantations by deer and medium-sized mammals in the Midwestern U.S. *Biomass and Bioenergy* 12(1):35-40.

De La Torre Ugarte, Daniel G. and Ray, Daryll E. 2000. Biomass and bioenergy applications of the POLYSYS modeling framework. *Biomass and Bioenergy*. 18(4):291-308.

DeLucchi, M.A. 1991. *Emissions of greenhouse gases from the use of transportation fuels and electricity,* Argonne National Laboratory, ANL/ESD/TM-22.

Elitzak, Howard, *Food Cost Review*, 1950-1997, U.S. Department of Agriculture, Economic Research Service, AER-780.

Food and Agricultural Policy Research Institute. 1999. *The rainbow book: a summary of the November 1998 FAPRI baseline.* University of Missouri, January 1999.

Graham, Robin L., Allison, L.J., and Becker. D.A. 1996. ORECCL - Oak Ridge energy crop county level database. *Proceedings of Bioenergy '96, Nashville, Tennessee, Sept. 15-19th, 1996*. Pages 522 to 529.

Hanowski, J.M., G.J. Niemi, D.P. Christian. 1997. Influence of within-plantation heterogeneity and surrounding landscape composition on avian communities in hybrid poplar plantations. *Conservation Biology* 11(4):936-944.

Ma, Z., C.W. Wood, D.I. Bransby. 2000. Carbon dynamics subsequent to establishment of switchgrass. *Biomass and Bioenergy* 18:93-104.

Mann, K., and Spath, P.L. 1999. The net $CO_2$ emissions and energy balances of biomass and coal-fired power systems. *Proceedings of the Fourth Biomass Conference of the Americas,* R.P. Overend and E. Chornet (eds.), Elsevier Science, Ltd., United Kingdom, pp 379-385.

McBride, William. 1996. *Datasets on machinery complements and machinery prices*. Economic Research Service, USDA.

Perry, C.H., R.C. Miller, and K.N. Brooks. 2000. Accepted for publication. Impacts of short-rotation woody crops on regional water yield. *Forest Ecology and Management.*

Schiller, A., W.A. Cresko, J.E. Lindberg, V.R. Tolbert. 2000. Bird communities on intensively managed forests from planting to harvest in the southeastern United States. Submitted to *Ecological Applications*.

Slinsky, Stephen P. and Tiller, Kelly H. 1999. Application of an alternative methodological approach for budget generators for research. Selected paper, published abstract. *Journal of Agricultural and Applied Economics*. 31(2):401.

Tolbert, V. R. and L. L. Wright. 1998. Environmental enhancement of U.S. biomass crop technologies: research results to date. *Biomass and Bioenergy* 15(1):93-100.

Tolbert, V. R., J. D. Joslin, F. C. Thornton, B. R. Bock, D. E. Pettry, W. Bandaranayake, D. Tyler, A. Houston, and S. Schoenholtz. 1999. Biomass crop production: benefits for soil quality and carbon sequestration. *Proceedings of the Fourth Biomass Conference of the Americas*, R.P. Overend and E. Chornet (eds.), Elsevier Science, Ltd., United Kingdom, pp. 127-132.

U.S. Department of Agriculture. *1997 Census of Agriculture.* National Agricultural Statistics Service, U.S. Department of Agriculture, March, 1999.

U.S. Department of Agriculture. 1997. *Agricultural baseline projections to 2008.* World Agricultural Outlook Board, Office of the Chief Economist, U.S. Department of Agriculture. Prepared by the Interagency Agricultural Projections Committee. Staff Report No. WAOB-99-1.

U.S. Department of Agriculture, Economic Research Service, 1999. *Feed Yearbook, FDS-1999*.

U.S. Department of Agriculture, Economic Resource Service, 2000. *Agricultural Outlook, AGO-268*.

U.S. Department of Energy, Energy Information Administration, *Annual Energy Review-1998*, July, 1999

U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook '99*

Walsh, Marie E. and D.A. Becker. BIOCOST: A software program to estimate the cost of producing bioenergy crops. *Proceedings of Bioenergy '96, Nashville, Tennessee, Sept. 15-19th, 1996*. Pages 480 to 486.

Wang, M., Saricks, C., and Santini, D. 1999. *Effects of fuel ethanol use on fuel-cycle energy and greenhouse gas emissions*, Argonne National Laboratory, ANL/ESD-38.

# APPENDICES

# Table of contents

# Appendix 1. List of participants

## POLYSYS Data Review Workshop
## Knoxville, TN
## November 19, 1997

**Dr. Larry Abrahamson**
State University of New York
College of Environmental Science and Forestry

**Dr. Dwayne Buxton**
USDA-ARS-NPS

**Ms. Janet Cushman**
Oak Ridge National Laboratory

**Dr. Robin Graham**
Oak Ridge National Laboratory

**Dr. John Hom**
USDA-FS

**Dr. Jud Isebrands**
North Central Forestry Experiment Station
Forestry Sciences Laboratory

**Dr. Sandy McLaughlin**
Oak Ridge National Laboratory

**Mr. Tien Nguyen**
U.S. Department of Energy

**Mr. Rick Pierce**
Champion International

**Dr. Daryll Ray**
The University of Tennessee Knoxville
Agricultural Policy Analysis Center

**Dr. Dan Robison**
Department of Forestry
North Carolina State University

**Dr. Hosein Shapouri**
Office of Energy and New Uses
USDA-ERS

**Mr. Steve Slinsky**
The University of Tennessee Knoxville
Agricultural Policy Analysis Center

**Mr. Mike Sullivan**
Champion International

**Mr. Alan Teel**
Iowa State University

**Dr. Kelly Tiller**
The University of Tennessee Knoxville
Agricultural Policy Analysis Center

**Dr. Jerry Tuskan**
Oak Ridge National Laboratory

**Dr. Daniel De La Torre Ugarte**
The University of Tennessee Knoxville
Agricultural Policy Analysis Center

**Dr. Ken Vogel**
USDA-ARS

**Dr. Marie Walsh**
Oak Ridge National Laboratory

**Ms. Lynn Wright**
Oak Ridge National Laboratory

## Appendix 2. Sources used in developing traditional crop production cost budgets

### Primary Data Source

| State | Level of Resolution of Information | Source |
|---|---|---|
| Alabama | Substate | USDA (Benson), The University of Tennessee (De La Torre Ugarte) |
| Arizona | Substate | Experiment Station |
| Arkansas | Substate | Extension Service |
| **California** | **Substate** | **USDA (Benson), Extension Service** |
| **Colorado** | **Substate** | **Extension Service** |
| **Connecticut** | **State** | **Neighboring State (NY)** |
| Delaware | State | Extension Service |
| Florida | State | Extension Service, The University of Tennessee (De La Torre Ugarte) |
| Georgia | State | USDA (Benson), The University of Tennessee (De La Torre Ugarte) |
| **Idaho** | **Substate** | **Extension Service** |
| **Illinois** | **State** | **USDA (Benson)** |
| **Indiana** | **Substate** | **Neighboring State (IL and OH)** |
| Iowa | State | USDA (Benson) |
| Kansas | State | USDA (Benson), Experiment Station (Kansas State University) |
| Kentucky | State | Neighboring State (TN), Extension Service |
| **Louisiana** | **Substate** | **Extension Service** |
| **Maine** | **State** | **Extension Service** |
| **Maryland** | **State** | **Extension Service** |
| Massachusetts | State | Neighboring State (NY) |
| Michigan | State | USDA (Benson), Neighboring State (MN And IL) |
| Minnesota | Substate | The University of Tennessee (English) |
| **Mississippi** | **Substate** | **Extension Service, The University of Tennessee (De La Torre Ugarte)** |
| **Missouri** | **Substate** | **USDA, NC214 Regional Project** |
| **Montana** | **Substate** | **Extension Service and Personal Communication (Zidack)** |
| Nebraska | Substate | Extension Service, NC214 (Baker), Personal Communication (Bernhardt) |
| Nevada | State | Neighboring State (UT) |
| New Hampshire | State | Neighboring State (NY) |
| **New Jersey** | **State** | **Neighboring State (PA)** |
| **New Mexico** | **State** | **USDA (Benson), Extension Service** |
| **New York** | **State** | **Extension Service** |
| North Carolina | State | USDA, The University of Tennessee (De La Torre Ugarte) |
| North Dakota | Substate | Neighboring States (MT, SD, and MN) |
| Ohio | Substate | Personal Communication (Batte) |
| **Oklahoma** | **State** | **USDA (Benson)** |
| **Oregon** | **Substate** | **Extension Service** |
| **Pennsylvania** | **State** | **Extension Service** |
| Rhode Island | State | Neighboring State (NY) |
| South Carolina | State | USDA, The University of Tennessee ((De La Torre Ugarte) |
| South Dakota | Substate | Extension Service and NC214 (Janssen) |
| **Tennessee** | **State** | **Extension Service, The University of Tennessee (De La Torre Ugarte)** |
| **Texas** | **Substate** | **USDA (Benson)** |
| Utah | State | USDA (Benson) |
| Vermont | State | Neighboring State (Maine) |
| Virginia | State | USDA |
| **Washington** | **Substate** | **Extension Service and Personal Communication** |
| **West Virginia** | **State** | **Neighboring State (VA)** |
| **Wisconsin** | **Substate** | **Neighboring States (MN and IL)** |
| Wyoming | State | Extension Service |

**Bold face type** used in listing to improve readability of appendix

## Personal Communication

**Kentucky** Isaacs, Steve. Personal Communication. University of Kentucky, Extension Economics. August 1995.

**Montana** Zidack, Walt. Personal Communication. Montana State University, Extension Economics. March 1996.

**Nebraska** Bernhardt, Kevin. Personal Communication. University of Nebraska (Lincoln), Department of Agricultural Economics. July 1994, March 1996.

**Ohio** Batte, Marvin. Personal Communication. Ohio State University, Department of Agricultural Economics. August 1994, March 1996.

**Washington** Painter, Kathleen. Personal Communication. Washington State University, Department of Agricultural Economics. April 1993, March 1996.

Young, Douglas. Personal Communication. Washington State University, Department of Agricultural Economics. January 1995.

## Extension Service

**Arizona** *Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Arkansas** Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, North of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 242. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, South of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 239. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, Furrow Irrigation, North of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 243. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, Furrow Irrigation, South of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 240. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, Center Pivot Irrigation, 130 Acres, South of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 241. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, Center Pivot Irrigation, 130 Acres, North of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 244. 1994.

Bryant, Kelly J., C.A. Stuart, and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Cotton: Loamy Soils, Solid Planted, Stale Seedbed, Furrow Irrigation, South of I-40, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 245. 1994.

Stuart, Clyde A., and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Corn: Loamy Soils, Flood Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 246. 1994.

Stuart, Clyde A., and T.E. *Windham. Estimating 1994 Production Costs in Arkansas – Corn: Loamy Soils, Furrow Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 247. 1994.

Stuart, Clyde A., and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Grain Sorghum: Clay Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 250. 1994.

Stuart, Clyde A., and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Grain Sorghum: Loamy Soils, Flood Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 249. 1994.

Stuart, Clyde A., and T.E. Windham. *Estimating 1994 Production Costs in Arkansas – Grain Sorghum: Loamy Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 248. 1994.

Stuart, Clyde A., T.E. Windham, and R.L. Rainey. *Estimating 1994 Production Costs in Arkansas – Rice: Silt Loam Soils, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 235. 1994.

Stuart, Clyde A., T.E. Windham, and R.L. Rainey. *Estimating 1994 Production Costs in Arkansas – Rice: Clay Soils, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 236.1994.

Stuart, Clyde A., T.E. Windham, and R.L. Rainey. *Estimating 1994 Production Costs in Arkansas – Rice: Grand Prairie Soils, Grand Prairie Region, Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 237. 1994.

Stuart, Clyde A., T.E. Windham, and R.L. Rainey. *Estimating 1994 Production Costs in Arkansas – Rice: Water Seeded, Eastern Arkansas.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 238. 1994.

Windham, Tony E., and C.A. Stuart. *Estimating 1994 Production Costs in Arkansas – Wheat: Clay Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 207. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Mixed Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 227. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Mixed Soils, Furrow Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 229. 1994

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Stale Seedbed, Mixed Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 228. 1994

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Following Rice, Loamy Soils, Flood Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 230. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Following Wheat, Loamy Soils, Flood Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 231. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: No-Till, Following Wheat, Loamy Soils, Flood Irrigation.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 232. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Narrow Row, Clay Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 233. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Narrow Row, Mixed Soils, Center Pivot Irrigation, Towable, 260 Acres.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 234. 1994.

Windham, Tony E., C.A. Stuart, and M.P. Mason. *Estimating 1994 Production Costs in Arkansas – Soybeans: Early Season, Loamy Soils.* University of Arkansas Cooperative Extension Service. Extension Technical Bulletin No. 226. 1994.

**California** *Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Colorado** Dalsted, Norman L., P.H. Gutierrez, D. Nitchie, R.L. Sharp, and J. Tranel. *Selected 1994 Crop Enterprise Budgets for Colorado.* Colorado State University Cooperative Extension. Report XCM-182. July 1995.

*Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report*. LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Delaware** Kee, Ed, Tracy Wootten, Laurie Wolinski, and Don Tilmon. *Vegetable and Agronomic Crop Budgets: 1995-1997*. Delaware Cooperative Extension Service, Extension Circular #152 Revised, 1997.

**Florida** Hewitt, Timothy D. *1994 Enterprise Budgets for Agronomic Crops.* University of Florida, Food and Resource Economics Department. 1994.

**Idaho** *Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

Rimbey, Neil R., M. Seyedbagheri, and R.L. Smathers. *1993 Southwestern Idaho Crop Enterprise Budgets.* University of Idaho Cooperative Extension System.

**Louisiana** Louisiana State University. *Projected Costs and Returns and Whole Farm Analysis for Major Agricultural Enterprises – Louisiana, 1995.* Department of Agricultural Economics and Agribusiness. AEA Information Series Nos. 126-133. January 1995.

**Maryland** University of Maryland. *Maryland Crop Budgets.* Maryland Cooperative Extension Service, 1992.

**Maine** Micka, Edward. *1985 Maine Farm Planning Guide*. Cooperative Extension Service University of Maine at Orono, 1985.

**Mississippi** Mississippi State University. *Corn and Grain Sorghum 1994 Planning Budgets.* Agricultural Economics Report 61. December 1993.

Mississippi State University. *Rice 1995 Planning Budgets.* Agricultural Economics Report 67. December 1994.

Mississippi State University. *Soybeans 1994 Planning Budgets.* Agricultural Economics Report 66. December 1994.

Mississippi State University. *Cotton 1995 Planning Budgets*. Agricultural Economics Report 65. December 1994.

Mississippi State University. *Wheat 1994 Planning Budgets.* Agricultural Economics Report 62. December 1993.

**Montana** Antle, John M., S.M. Capalbo, J.B. Johnson, and W.E. Zidack. *Montana Sustainable Agriculture Economic Impact Study: Physical and Economic Crop Production Data.* Montana State University. February 1995.

*Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Nebraska** Bitney, Larry L., R.T. Clark, D.E. Ellis, H.D. Jose, D.J. Kabes, R.N. Klein, R.E. Massey, and T.A. Powell. *Nebraska Crop Budgets: 1994.* Nebraska Cooperative Extension. Report EC94-872-S. 1994.

**New York** Snyder, Darwin. *Field Crop Enterprise Budget Update: 1990 Cost and Return Projections and Grower Worksheets, New York State.* Cornell University Agricultural Extension Service, A.E. Res. 90-7. May 1990.

**New Mexico** *Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Oregon** Aldrich-Markham, Susan. *Enterprise Budget: Spring Oats, Willamette Valley Region.* Oregon State University Extension Service, EM 8592. April 1995.

Cross, Tom, and B. Smith. *Enterprise Budget: Corn, Irrigated, North Central Region.* Oregon State University Extension Service, EM 8458. March 1991.

Cross, Tom, B. Smith, and M. Taylor. *Enterprise Budget: Wheat, Irrigated, North Central Region.* Oregon State University Extension Service, EM 8456. March 1991.

Kerns, Loren, M. Stoltz, B. Eleveld, and R. Karow. "Enterprise Budget: *Wheat (Winter) Following Farrow, Pendleton Area.* Oregon State University Extension Service, EM 8634. October 1995.

*Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

Vermilyea, Dian, G. Cook, and K. Vermilyea. *Enterprise Budget: Irrigated Winter Wheat, Eastern Oregon Region.* Oregon State University Extension Service. EM 8607. July 1995.

**Pennsylvania** The Pennsylvania State University. *Crop Budgets and Guides for Choosing Cropping Systems.* Cooperative Extension, 1990.

**South Dakota** Peterson, Donald L. *1994 Estimated Costs of Production for Spring Crops: West Central South Dakota.* South Dakota State University, Cooperative Extension Service. Report EMC 937. March 1994

Peterson, Donald L. *1994 Estimated Costs of Production for Spring Crops: Southeast South Dakota.* South Dakota State University, Cooperative Extension Service. Report EMC 932. March 1994

Peterson, Donald L. *1994 Estimated Costs of Production for Spring Crops: Central South Dakota.* South Dakota State University, Cooperative Extension Service. Report EMC 934. March 1994

Peterson, Donald L. *1994 Estimated Costs of Production for Spring Crops.* South Dakota State University, Cooperative Extension Service. Report EMC 937. March 1994

South Dakota State University. *1995 Winter Wheat Budgets for South Dakota.* Cooperative Extension Service. Report EMC 928. September 1994.

**Tennessee** Johnson, Larry A. *Guide to Farm Planning.* The University of Tennessee. EC 622. September 1991.

Johnson, Larry A. *Conventional and Sustainable Agriculture Enterprise and Systems Budgets for Southern Limited Resource Farms.* The University of Tennessee. December 1992.

The University of Tennessee. *Field Crop Budgets for 1996.* Agricultural Extension Service, Agricultural Economics and Resource Development. AE&RD Information Bulletin No. 55. February 1996.

**Texas** Amosson, Stephen H., and J.G. Smith. *Texas Crop Enterprise Budgets: Texas Panhandle & South Plains Districts, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C01).

Bevers, Stanley J. *Texas Crop Enterprise Budgets: Texas Rolling Plains District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C03).

Cornforth, Gerald C. *Texas Crop Enterprise Budgets: Central Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C08).

Falconer, Lawrence L. *Texas Crop Enterprise Budgets: Texas Coastal Bend District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C11).

Gerlow, Arthur R. *Texas Crop Enterprise Budgets: Southeast Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C09).

Peña, José G. *Texas Crop Enterprise Budgets: Southwest Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C10).

Stokes, Kenneth W. *Texas Crop Enterprise Budgets: North Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C04).

Taylor, Merritt J. *Texas Crop Enterprise Budgets: South Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C12).

The Texas Agricultural Extension Service. *Texas Crop Enterprise Budgets: Far West Texas District, Projected for 1995.* The Texas Agricultural Extension Service. Report B-1241(C06).

**Utah**

*Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Washington**

Painter, Kathleen, D. Granatstein, and B. Miller. *1992 Alternative Crop Rotation Enterprise Budgets, Eastern Whitman County, Washington.* Washington State University Cooperative Extension. Farm Business Management Report EB1725.

*Project: Total Resource Budgeting of LISA Farm Enterprises – Final Report.* LISA-funded project. Western Farm Management Extension Committee. August 1992.

**Wyoming**

Hewlett, John P., P.A. Burgener, and J.J. Jacobs. *Enterprise Budget: Alfalfa Establishment, Powell Area.* University of Wyoming. MP-70.1. August 1991.

Hewlett, John P., P.A. Burgener, and J.J. Jacobs. *Enterprise Budget: Alfalfa Hay, Baled, Powell Area.* University of Wyoming. MP-70.2. August 1991.

Hewlett, John P., P.A. Burgener, and J.J. Jacobs. *Enterprise Budget: Alfalfa Establishment, Powell Area.* University of Wyoming. MP-70.2. August 1991.

Hewlett, John P., P.A. Burgener, and J.J. Jacobs. *Enterprise Budget: Malting Barley, Powell Area.* University of Wyoming. MP-70. August 1991.

Hewlett, John P., and C. Bastian. *Enterprise Budget: Corn for Grain, Wheatland Area.* University of Wyoming. MP-72.4. June 1992.

Hewlett, John P., and C. Bastian. *Enterprise Budget: Alfalfa Hay, Baled, Wheatland Area.* University of Wyoming. MP-72.41. June 1992.

Hewlett, John P., and C. Bastian. *Enterprise Budget: Alfalfa Establishment, Wheatland Area.* University of Wyoming. MP-72. June 1992.

Hewlett, John P., and C. Bastian. *Crop Enterprise Budget: Dry Beans, Wheatland Area.* University of Wyoming. MP-72.2. June 1992.

Hewlett, John P., and C. Bastian. *Crop Enterprise Budget: Sugar Beets, Thick-Planted, Wheatland Area.* University of Wyoming. MP-72.3. June 1992.

Hewlett, John P., and C. Bastian. *Crop Enterprise Budget: Corn for Silage, Wheatland Area.* University of Wyoming. MP-72.5. June 1992.

Hewlett, John P., and C. Bastian. *Crop Enterprise Budget: Setaside Program, Wheatland Area.* University of Wyoming. MP-72.6. June 1992.

University of Wyoming. *Costs of Producing Crops: Worland Area, Wyoming, 1985-86.* Cooperative Extension Service, Report No. B 644R. July 1986.

University of Wyoming. *Costs of Producing Dryland Winter Wheat on Summer Fallow, Southeastern Wyoming, 1975-76.* Agricultural Extension Service, Division of Agricultural Economics. Bulletin 634. November 1975.

## U.S. Department of Agriculture

Benson, Verel. Unpublished data sets and personal communication. Economist, Natural Resources Conservation Service. 1993.

U.S. Department of Agriculture. *Usual Planting and Harvesting Data for U.S. Field Crops.* USDA Statistical Reporting Service. Agricultural Handbook No. 628. April 1984.

## The University of Tennessee

De La Torre Ugarte, S.P. Slinsky, J. Hamrick, D.E. Ray, and R.L. White. *Economic and Environmental Impacts of Movement Toward a More Sustainable Agriculture on the Southeastern United States: Final Report.* The University of Tennessee. ACE Project No. 43-3AEK-3-88078. June 1996.

English, Burton C. Department of Agricultural Economics and Rural Sociology, The University of Tennessee. Unpublished data for a U.S. Department of Energy-funded study to develop a GIS-based system of analyzing biomass potential in the Midwest and the Southeastern United States. 1995.

## Experiment Stations

Kansas — Kansas State University. *An Economic Analysis of Conventional and Alternative Cropping Systems for Northeast Kansas.* Agricultural Experiment Station, Report of Progress 687. September 1993.

Arizona — *Arizona County Level Crop Budgets.* Arizona State University, Department of Agricultural and Resource Economics. World Wide Web URL: http://ag.arizona.edu/AREC/budgets/counties/html.

## NC214 Regional Project Group

Nebraska — Baker, Maurice. Personal Communication. University of Nebraska (Lincoln), Department of Agricultural Economics. April 1995, April 1996.

South Dakota — Janssen, Larry. Personal Communication. South Dakota State University, Economics Department. December 1994.

# Appendix 3: Bioenergy Crops Management Practices

## Appendix 3.1: Management Practices for Bioenergy Crops on Cropland Acres Currently Planted to Traditional Crops

(SE = Southeast; App = Appalachia; CB = Corn Belt; LS = Lake States; NP = North Plains; SP = South Plains; PNW = Pacific Northwest; NE = Northeast)

I. Switchgrass
  A. Establishment Year
    1. 1x disk, 1.15x grain drill
    2. 5.75 lb seed/acre (Alamo in SE, APP, SP; Cave-in-Rock in NP; Pathfinder in CB, LS)
    3. 1x lime (1 ton/ac in LS, CB; 2 ton/ac in SE, APP; 0 Elsewhere).
    4. 1x P (15 lb/ac P in all regions) and N (20 lb/dry ton yield in SE; 25 lb/dt yield in SP; 0 elsewhere).
    5. 1x 2,4-D (1 lb a.i./acre in all regions)
    6. 1x Plateau (2 lb a.i./acre in all regions)
    7. 1x harvest (mow, rake, 4x6 round bale, move to side of field and stack)
    8. Yield is 30 percent of expected average annual yield
  B. Maintenance Years (Years 2-10)
    1. 1x K (25 lb/ac in years 3, 6, and 9 east of the Mississippi River; no K west of the Mississippi River) and N (25 lb/dry yield ton annually in SP; 20 lb/dry ton yield annually elsewhere)
    2. 1x harvest annually (mow, rake, 4x6 round bale, move to side of field and stack)
    3. Yield is 67 percent of expected yield in year 2 and 100 percent in yrs. 3-10
    4. In year 10 following harvest, 1x application glyphosate (2 lb a.i./acre)

II. Hybrid Poplar
  A. Establishment Year
    1. 2x disk
    2. Manual planting of cuttings (8' x 10' spacing; 545 trees/acre; $0.24/cutting-planting)
    3. 1x Fusilade (quart/acre) or Transline (pint/acre) in all regions
    4. 1x Linuron (1.5 lb a.i./acre in LS) or 1x Oust (0.15 lb a.i./acre elsewhere)
    5. 3x cultivations
  B. Maintenance Years
    1. 1x N (75 lb/ac in yr 3 in PNW; 75 lb/ac in yr 4 elsewhere)
    2 1x lime in yr 3 (1 ton/ac in SE, APP; 1.5 ton/acre in NP, SP; none elsewhere)
    3. 1x K in yr 3 (35 lb/ac in LS; 50 lb/ac in CB, APP; 40 lb/ac in SE; 15 lb/ac in NP, PNW; and 25 lb/ac SP) and 1x P in yr 3 (20 lb/ac in LS, SE, PNW; 15 lb/ac in NP, SP; 25 lb/ac in APP; 50 lb/ac in CB)
    4. 2x cultivation in yr 2 (all regions but PNW where it is 1x)
    5. 1x cultivation in yr 3 (all regions but PNW where it is 0x)
    6. 1x Seven in yr 2 (all regions but PNW where it is 0x)
    7. 1x harvest (feller buncher, skid, chip, blow into truck) (yr 10 in LS, CB, NP, NE; yr 8 in SE, SP; yr 6 in PNW)
    8. Following harvest, 1x glyphosate (2 lb a.i./ac) - forestry disk

III. Willow
  A. Establishment Year
    1. 2x disk
    2. Mechanical planting (6200 trees/acre; $0.10/cutting; $0.02/cutting to plant)
    3. 1x glyphosate (2 lb a.i./acre)
    4. 1x Goal (1 lb a.i./acre)
  B. Maintenance Years (Years 2-22)
    1. 1x N (100 lb/ac in yrs 2, 5, 8, 11, 14, 17, 20)
    2. 1x harvest in yrs 4, 7, 10, 13, 16, 19, 22 (Claas-Jaguar; blow into trailer; load into chip van)
    3. After final harvest, 1x glyphosate (2 lb a.i./ac), 2x heavy forestry disk, 1x harrow rake
    4. Yield is 60 percent expected yield in yr 4 and 100 percent expected yield thereafter

## Appendix 3.2: Management Practices for Bioenergy Crops on Cropland Acres Currently Idled or Planted to Pasture

(SE = Southeast; App = Appalachia; CB = Corn Belt; LS = Lake States; NP = North Plains; SP = South Plains; PNW = Pacific Northwest; NE = Northeast)

I. Switchgrass
   A. Establishment Year
      1. 1x glyphosate (2 lb a.i./ac)
      2. 2x disk
      3. 1.15 grain drill
      4. 5.75 lb seed/acre (Alamo in SE, APP, SP; Cave-in-Rock in NP; Pathfinder in CB, LS)
      5. 1x lime (1 ton/ac in LS, CB; 2 ton/ac in SE, APP; 0 Elsewhere).
      6. 1x P (15 lb/ac P in all regions) and N (20 lb/dry ton yield in SE; 25 lb/dt yield in SP; 0 elsewhere)
      7. 1x Plateau (2 lb a.i./acre in all regions)
      8. 1x harvest (mow, rake, 4x6 round bale, move to side of field and stack)
      9. Yield is 30 percent of expected average annual yield
   B. Maintenance Years (Years 2-10)
      1. 1x K (25 lb/ac in years 3, 6, and 9 east of the Mississippi River; no K west of the Mississippi River) and N (25 lb/dry yield ton annually in SP; 20 lb/dry ton yield annually elsewhere)
      2. 1x harvest annually (mow, rake, 4x6 round bale, move to side of field and stack)
      3. Yield is 67 percent of expected yield in year 2 and 100 percent in yrs. 3-10
      4. In year 10 following harvest, 1x application glyphosate (2 lb a.i./acre)

II. Hybrid Poplar
   A. Establishment Year
      1. 1x glyphosate (2 lb a.i./ac)
      2. Moldboard plow, 2x disk
      3. Manual planting of cuttings (8' x 10' spacing; 545 trees/acre; $0.24/cutting)
      4. 1x Fusilade (quart/acre) or Transline (pint/acre) in all regions
      5. 3x cultivations
   B. Maintenance Years
      1. 1x N (75 lb/ac in yr 3 in PNW; 75 lb/ac in yr 4 elsewhere)
      2. 1x lime in yr 3 (1 ton/ac in SE, APP; 1.5 ton/acre in NP, SP; none elsewhere)
      3. 1x K in yr 3 (35 lb/ac in LS; 50 lb/ac in CB, APP; 40 lb/ac in SE; 15 lb/ac in NP, PNW; and 25 lb/ac SP) and 1x P in yr 3 (20 lb/ac in LS, SE, PNW; 15 lb/ac in NP, SP; 25 lb/ac in APP; 50 lb/ac in CB)
      4. 2x cultivation in yr 2 (all regions but PNW where it is 1x)
      5. 1x cultivation in yr 3 (all regions but PNW where it is 0x)
      6. 1x Seven in yr 2 (all regions but PNW where it is 0x)
      7. 1x harvest (feller buncher, skid, chip, blow into truck) (yr 10 in LS, CB, NP, NE; yr 8 in SE, SP; yr 6 in PNW)
      8. Following harvest, 1x glyphosate (2 lb a.i./ac)

III. Willow
   A. Establishment Year
      1. 2x disk
      2. Mechanical planting (6200 trees/acre; $0.02/cutting)(0.10/cutting; 0.02/cutting to plant)
      3. 1x glyphosate (2 lb a.i./acre)
      4. 1x Goal (1 lb a.i./acre)
   B. Maintenance Years (Years 2-22)
      1. 1x N (100 lb/ac in yrs 2, 5, 8, 11, 14, 17, 20)
      2. 1x harvest in yrs 4, 7, 10, 13, 16, 19, 22 (Claas-Jaguar; blow into trailer; load into chip van)
      3. After final harvest, 1x glyphosate (2 lb a.i./ac), 2x heavy forestry disk, 1x harrow rake
      4. Yield is 60 percent expected yield in yr 4 and 100 percent expected yield thereafter

## Appendix 3.3: Management Practices of Bioenergy Crops on Conservation Reserve Program Acres

**I. CRP Acres under the Production Management Scenario**

A. This scenario assumes that upon expiration of current CRP contracts:
  1. The same acres are reenrolled in a CRP program at 75% of the rental rate that they currently receive.
  2. The acres will be allowed to be replanted into switchgrass, poplar, or willow.
  3. Government sharing of establishment costs is not assumed.
  4. Annual harvest is allowed.
  5. Management practices to encourage high biomass yields are used.
  6. Early out options with no penalty is allowed.

B. CRP acres allowed to be harvested include all acres currently enrolled in CRP program in designated geographic areas for biomass energy crop production except:
  1. Acres in special uses categories (riparian buffers, filter strips, windbreaks, wetlands, etc.)
  2. Acres designated as essential to maintaining water quality in watersheds
  3. Acres designated as essential to maintaining critical wildlife habitat in high priority wildlife regions (i.e., Prairie Pothole region, etc.)

C. Management practices:
  1. Acres replanted to high yielding switchgrass or poplar or willow varieties suitable to region
  2. Herbicide applications the same as for non-CRP biomass acres
  3. Fertilizer applications applied in same years as for non-CRP biomass acres at the same rate for poplar and willow. For switchgrass, P, K, and lime applied as for non-CRP acres and nitrogen applied at a rate of 10 lb/ton expected yield for switchgrass everywhere but in the South Plains where the rate is 15 lb/ton expected yield

D. Harvest Practices:
  1. For switchgrass, annual harvest of entire field is allowed, 4-6" height.
  2. For poplar and willow, harvest of entire field in same years as for non-CRP acres.

E. Biomass yields on CRP acres are adjusted relative to yields on non-CRP acres using a crop efficiency index provided by FSA

**II. CRP Acres under the Wildlife Management Scenario**

A. This scenario assumes that upon expiration of current CRP contracts,
  1. The same acres are reenrolled in the CRP program at 75% of the rental rate that they currently receive.
  2. The acres will be allowed to be replanted into switchgrass, poplar, or willow.
  3. No government sharing of establishment costs is assumed.
  4. Management practices to ensure high wildlife diversity are used.
  5. Early out options with no penalties are allowed.

B. CRP acres allowed to be harvested include all acres currently enrolled in CRP program in designated geographic areas for biomass energy crop production except:
  1. Acres in special uses categories (riparian buffers, filter strips, windbreaks, wetlands, etc.)
  2. Acres designated as essential to maintaining water quality in watersheds
  3. Acres designated as essential to maintaining critical habitat in high priority wildlife regions (i.e., Prairie Pothole region, etc.)

C. Management practices:
  1. Acres replanted to high yielding switchgrass or poplar or willow varieties suitable to region. Planting will use no-till operations. Poplar and willow will be planted with a cover crop.
  2. Glyphosate herbicide application of 2 lb a.i. in establishment year
  3. Nitrogen fertilizer applied every 3 years beginning in year 2 to switchgrass at a rate of 10 lb/expected ton in all regions but the South Plains where the rate is 15 lb/expected ton. Nitrogen applied to poplar and willow as on non-CRP acres. P and K added as on non-CRP acres for all biomass crops. No lime added for any biomass crop.
  4. Cover crop of annual ryegrass planted with switchgrass and poplar and willow at a rate of 3 lb/ac and 5 lb/ac respectively.

D. Harvest Practices:

1. Harvest will be every 3 years for willow and after 10 years for poplar.
2. For switchgrass half of the field will be harvested in years 3, 5, 7, and 9 and the other half will be harvested in years 4, 6, 8, and 10 at a height of 6-8".

E. Biomass yields are adjusted by an index of crops on CRP acres compared to non-CRP acres

**Appendix 4. Regional Net Present Value production costs and returns for bioenergy crops (per acre)(price=$2.58/MBtu)**

| | Northeast | | | Appalachia | | |
|---|---|---|---|---|---|---|
| | Switchgrass | Poplars | Willows | Switchgrass | Poplars | Willows |
| Mature Yield | 4.87 | 39.87 | 16.23 | 5.84 | 35.77 | 15.00 |
| Revenue | $1,246.16 | $976.69 | $2,176.78 | $1,494.37 | $984.55 | $2,011.82 |
| Seed Cost | $27.93 | $123.40 | $701.89 | $27.93 | $123.40 | $701.89 |
| Fertilizer N | $240.39 | $23.99 | $158.20 | $260.95 | $21.73 | $144.93 |
| Fertilizer P | $4.26 | $6.33 | $0.00 | $4.02 | $5.98 | $0.00 |
| Fertilizer K | $6.82 | $5.36 | $0.00 | $7.30 | $5.73 | $0.00 |
| Fertilizer Lime | $47.15 | $20.98 | $0.00 | $45.33 | $20.18 | $0.00 |
| PH* Chemical | $13.09 | $34.76 | $88.11 | $13.09 | $34.76 | $88.11 |
| PH Labor | $15.50 | $15.92 | $7.66 | $13.01 | $13.20 | $6.45 |
| PH Mach Var | $24.16 | $21.23 | $7.98 | $19.28 | $18.94 | $8.25 |
| PH Mach Fixed | $33.79 | $27.72 | $11.55 | $27.31 | $25.30 | $11.88 |
| Interest OPI | $15.95 | $166.15 | $238.66 | $16.54 | $143.92 | $235.80 |
| Harvest Cost | $523.02 | $403.74 | $956.27 | $504.81 | $481.57 | $934.22 |
| CU* Chemical | $25.44 | $25.44 | $12.64 | $25.44 | $28.58 | $12.64 |
| CU Labor | $0.94 | $3.94 | $2.24 | $0.79 | $3.67 | $1.89 |
| CU Mach Var | $1.93 | $14.91 | $7.53 | $1.43 | $15.37 | $6.79 |
| CU Mach Fixed | $2.78 | $26.52 | $13.59 | $2.25 | $25.24 | $10.88 |
| Total Cost | $983.14 | $920.38 | $2,206.33 | $969.50 | $967.56 | $2,163.76 |
| Returns | $263.02 | $56.31 | ($29.55) | $524.86 | $16.99 | ($151.94) |

| | Corn Belt | | | Lake States | | |
|---|---|---|---|---|---|---|
| | Switchgrass | Poplars | Willows | Switchgrass | Poplars | Willows |
| Mature Yield | 5.98 | 46.26 | 15.80 | 4.80 | 44.06 | 15.34 |
| Revenue | $1,530.19 | $1,133.22 | $2,119.11 | $1,228.25 | $1,079.33 | $2,057.42 |
| Seed Cost | $10.85 | $123.40 | $701.89 | $10.85 | $123.40 | $701.89 |
| Fertilizer N | $243.60 | $19.79 | $130.51 | $195.66 | $19.79 | $130.51 |
| Fertilizer P | $3.92 | $11.63 | $0.00 | $3.92 | $4.65 | $0.00 |
| Fertilizer K | $4.05 | $5.31 | $0.00 | $4.50 | $3.72 | $0.00 |
| Fertilizer Lime | $12.04 | $0.00 | $0.00 | $12.04 | $0.00 | $0.00 |
| PH* Chemical | $13.09 | $34.76 | $88.11 | $13.09 | $32.89 | $88.11 |
| PH Labor | $14.82 | $15.07 | $7.22 | $16.14 | $16.43 | $7.79 |
| PH Mach Var | $24.03 | $20.56 | $8.23 | $24.80 | $20.55 | $7.96 |
| PH Mach Fixed | $35.48 | $27.92 | $12.16 | $36.12 | $27.02 | $11.82 |
| Interest OPI | $13.69 | $155.13 | $233.04 | $11.74 | $147.80 | $233.12 |
| Harvest Cost | $569.02 | $435.20 | $945.32 | $502.85 | $425.70 | $937.70 |
| CU* Chemical | $25.44 | $25.44 | $12.64 | $25.44 | $25.44 | $12.64 |
| CU Labor | $0.90 | $3.73 | $2.11 | $0.98 | $4.07 | $2.28 |
| CU Mach Var | $1.90 | $14.36 | $7.29 | $1.97 | $14.96 | $7.42 |
| CU Mach Fixed | $2.89 | $24.98 | $12.77 | $2.95 | $26.39 | $13.07 |
| Total Cost | $975.75 | $917.26 | $2,161.30 | $863.10 | $892.82 | $2,154.30 |
| Returns | $554.44 | $215.96 | ($42.19) | $365.14 | $186.51 | ($96.88) |

*PH - Pre Harvest
*CU - Post Harvest

| | Southeast | | Southern Plains | | Northern Plains | | Pacific Northwest |
|---|---|---|---|---|---|---|---|
| | Switchgrass | Poplars | Switchgrass | Poplars | Switchgrass | Poplars | Poplars |
| Mature Yield | 5.49 | 36.00 | 4.30 | 30.01 | 3.47 | 38.31 | 34.37 |
| Revenue | $1,404.81 | $990.88 | $1,100.30 | $826.01 | $887.92 | $960.22 | $1,062.95 |
| Seed Cost | $27.93 | $123.40 | $27.93 | $123.40 | $10.85 | $123.40 | $123.40 |
| Fertilizer N | $248.11 | $21.02 | $249.77 | $19.61 | $149.75 | $18.67 | $23.38 |
| Fertilizer P | $3.98 | $4.72 | $3.90 | $3.47 | $3.98 | $3.54 | $5.28 |
| Fertilizer K | $7.20 | $4.52 | $0.00 | $2.61 | $0.00 | $1.65 | $1.95 |
| Fertilizer Lime | $44.21 | $19.68 | $0.00 | $29.87 | $0.00 | $22.04 | $0.00 |
| PH* Chemical | $13.09 | $34.76 | $13.09 | $34.76 | $13.09 | $34.76 | $33.14 |
| PH Labor | $13.03 | $13.24 | $12.45 | $12.73 | $15.49 | $15.73 | $10.51 |
| PH Mach Var | $20.20 | $19.44 | $20.61 | $19.49 | $24.87 | $20.88 | $16.30 |
| PH Mach Fixed | $29.38 | $26.33 | $28.95 | $27.01 | $37.40 | $28.93 | $22.23 |
| Interest OPI | $15.96 | $143.38 | $14.11 | $145.43 | $9.69 | $157.96 | $93.09 |
| Harvest Cost | $476.44 | $481.53 | $445.97 | $433.49 | $405.86 | $400.78 | $624.69 |
| CU* Chemical | $25.44 | $28.58 | $25.44 | $28.58 | $25.44 | $26.03 | $32.12 |
| CU Labor | $0.79 | $3.68 | $0.76 | $3.54 | $0.94 | $4.00 | $4.85 |
| CU Mach Var | $1.50 | $15.93 | $1.75 | $16.23 | $1.97 | $15.25 | $20.84 |
| CU Mach Fixed | $2.43 | $27.35 | $2.65 | $28.55 | $3.09 | $27.13 | $39.30 |
| Total Cost | $929.73 | $967.57 | $847.37 | $928.78 | $714.25 | $900.74 | $1,051.08 |
| Returns | $475.08 | $23.32 | $252.93 | ($102.76) | $173.67 | $59.48 | $11.87 |

*PH - Pre Harvest
*CU - Post Harvest